Evaluation of Cleaning and Rehabilitation of University of Idaho Well #2 on the Local Groundwater Systems, in the Moscow, Idaho Area.

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AUTHORIZATION TO SUBMIT

THESIS

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ABSTRACT

The setting of this project was in Moscow, Idaho USA on the University of Idaho campus. The project was focused around the University of Idaho Well #2 which was discovered to be naturally draining ground water downward from the upper to the lower portion of an aquifer system, based on a 2004 borehole video documentation. Well UI#2 was cleaned and rehabilitated in order to increase the flow in the borehole.

A monitoring plan was designed to monitor changes in the ground water flow environment around well UI#2 as a result of the additional ground water exchanged within the aquifer system. Monitoring of water levels and water temperatures began in January 2006 and ended in March 2006 in systems that were expected to be affected by cleaning well UI#2.

Cleaning activities in well UI#2 occurred from February 10, 2006 to February 15, 2006. The timing of specific events during cleaning activities were used to relate to changes that were observed in the monitored water temperatures and water levels in monitoring wells.

The timing of changes in monitored water levels initially appeared to coincide with cleaning activities. Comparison of water levels and water temperatures from Paradise Creek and a shallow sediment aquifer did not provide evidence that cleaning well UI#2 had any affect. Monitored water levels deeper in the aquifer system responded to a spike in stream stage which caused a ground water recharge event. The event affected monitored water levels in both the upper and lower portions of the aquifer system.

ACKNOWLEDGMENTS

I would like to express my gratitude to my major professor Jim Osiensky for the utmost guidance throughout this project. Special thanks to my committee members Jerry Fairley, and Tim Link for advice and direction throughout my academic career. I would also like to thank my fellow hydrology and geology graduate students for their encouragement and understanding. I would like to acknowledge PBAC for funding this project and realizing the importance of funding graduate research. Finally, I wish to express my deepest appreciation to my mother and father for their ever enduring patience and support.

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CHAPTER 1 INTRODUCTION

This thesis research was conducted to evaluate the potential use of University of Idaho Well #2 (UI#2) for passive groundwater recharge to the lower Wanapum aquifer system. The study was intended to demonstrate the feasibility of increasing groundwater recharge by moving groundwater from the upper portion of the Wanapum aquifer system to the lower portion of the Wanapum aquifer system via the decommissioned UI#2 production well.

1.1 Construction and Decommission of University of Idaho Well #2

The following section is the chronology of the University of Idaho Well #2, from when it was completed until the actions taken by University of Idaho to decommission the well. Information was gathered from the well log for UI#2 and from verbal communication with others involved in this project. The sequence of certain details contained in the well log does not follow a typical production well development plan. This researcher is not responsible for any false information that maybe contained in the well log for UI#2. This disclaimer is grounded from the fact that all modifications to well UI#2 over eight years were added to a single geologic well log and construction sheet. Separate well log schematics may exist for each modification to UI#2; however; no knowledge of the existence of such a compilation of information exists at this time.

Well UI#2 was completed in February 1951 on the University of Idaho Campus located in Moscow, ID. The UI campus is the area shaded in pink in Figure 1.1, and the location of UI#2 pump house is located on the map below.

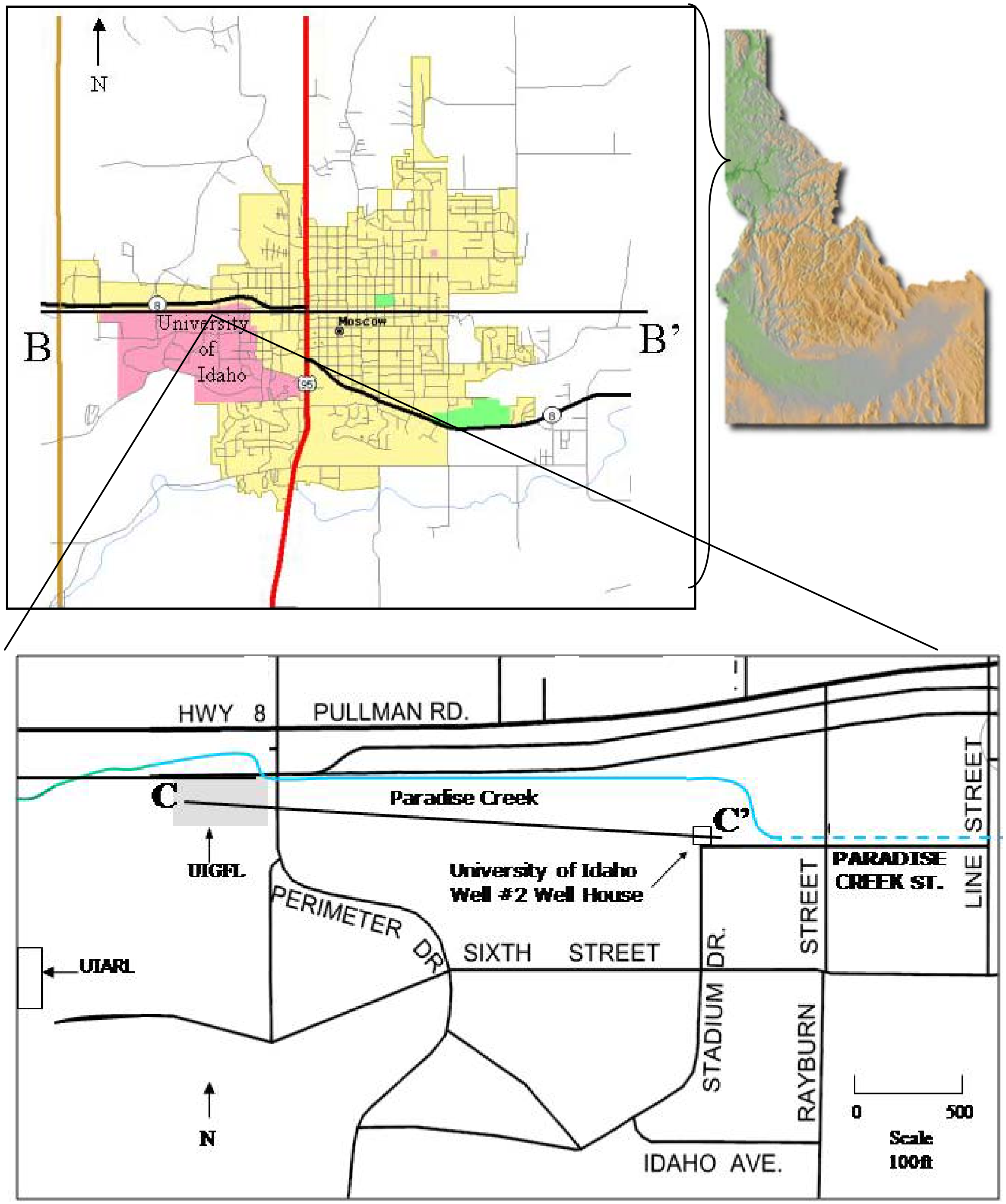

Figure 1. 1 Location map of study area. The city of Moscow is located in the northwest portion of the state of Idaho in the region know as the Palouse. The University of Idaho Campus is located on the southwest side of Moscow. The campus borders US Highway 95 to the east and State Highway 8 to the north. The UI2 well house is on the corner of Stadium Dr. and Paradise Creek St. B-B' represents the location of the cross section shown in Figure 2.6. C-C' represents the cross section shown in Figure 3.10.

The total depth of the well UI#2 was 354 feet below land surface (fbls) upon final completion in February 1951. A 16-inch diameter steel casing was set from land surface to a depth of 167 fbls. A reduced 12-inch steel diameter casing was set from 167 ft to 354 fbls. According to the well log, the pumping rate during the development of well UI#2 was 2000 gallons per minute (gpm) on February 25, 1951. The static water level before pumping was 55 fbls and the drawdown level during the test was 104 fbls. The water level recovered to 64 fbls after pumping. The results of pumping caused sediments to fill in the well to a depth of 241 fbls. In September 1951, the 113 feet of accumulated sediments were removed and 20-inch diameter steel casing was then set from land surface to a depth of 350 feet. It is assumed that the 20-inch diameter casing was installed in an attempt to prevent the influx of sediments during pumping; however, no information is present on the well log to explain how this was accomplished. The 20-inch diameter casing was perforated at the same intervals as the 16 and 12-inch inner casings (Figure 1.2).

UI#2 was placed back on line and used as a university production well. Well UI#2 had a pumping capacity of 500 gpm. University water managers felt it was necessary to measure the amount of accumulated sediments at the bottom of the well periodically. On May 13, 1952, the static water level was 57 fbls and the bottom of the well was at a depth of 339 fbls. UI#2 had accumulated 11 feet of sediments over an eight-month period. No action was taken to remove these sediments according to the well log notes.

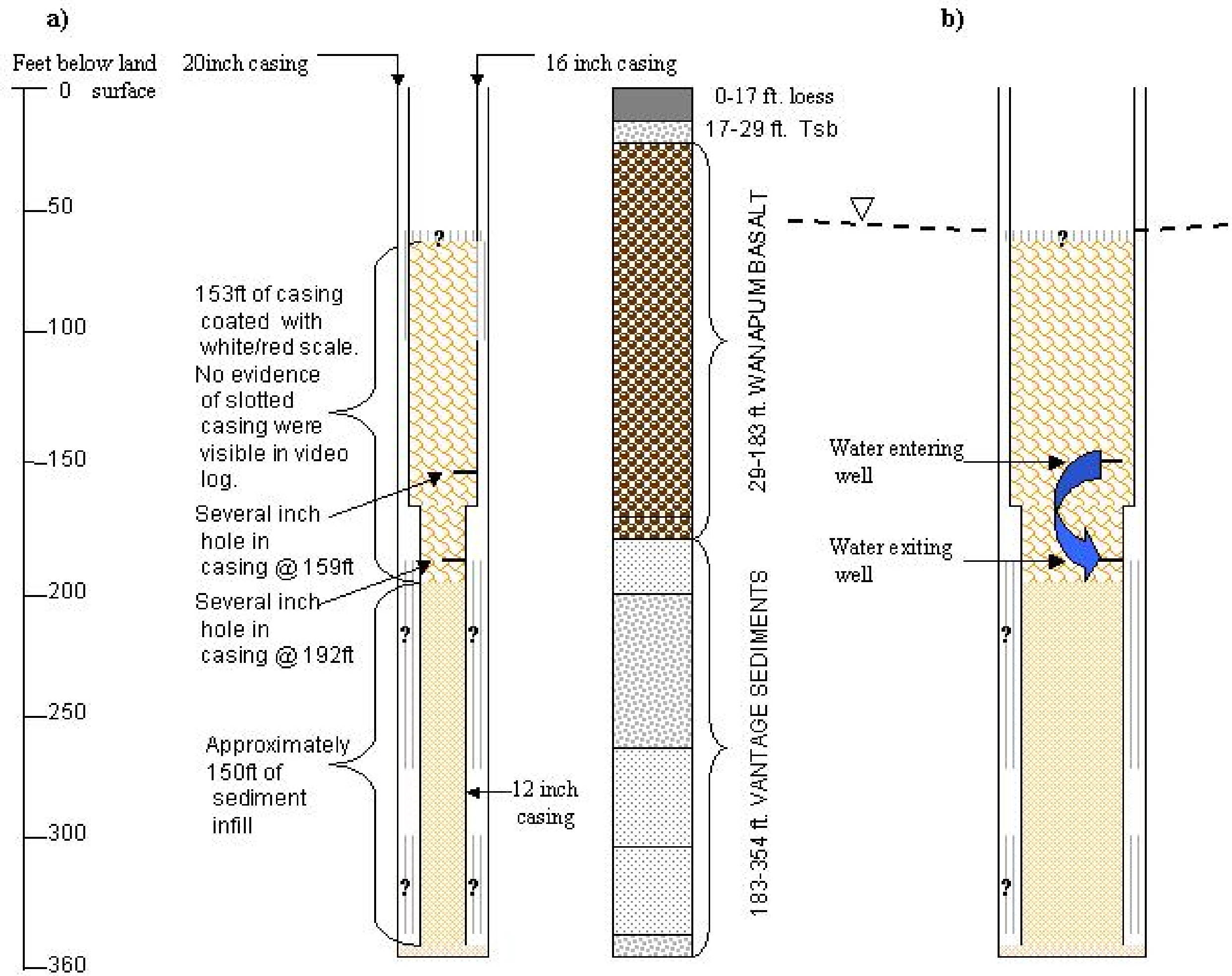

Figure 1. 2 Well UI#2 borehole conditions before cleaning. a) Conditions of well UI2 based on 2004 borehole video. Original well casing slots were not visible. b) Pattern of water flow seen in borehole video. Suspended particles could be seen clearly exiting the borehole through a hole in the casing at a depth of 192 fbls.

The accumulated sediments were measured on February 22, 1956. The bottom of the well was at a depth of 334 fbls. No static water level measurement was documented. No action was taken for the additional accumulated sediments.

Nearly two years later on January 8, 1958, 25 feet of sediments were bailed out of the bottom 12-inch casing in well UI#2. The static water level was 75 fbls after bailing was completed. On January 9, 1958, the bottom of the well was 343 fbls. The well manager decided on January 10, 1958 to add 20 feet of pump column. Lowering the pump may have been done to help prevent the water level in the well from drawing down to the impellers of the pump. The final note documented in this section of the UI#2 well log is dated December 17, 1958. At that time, the static water level in the well was 98 fbls.

After December 1958, a record exists in the University of Idaho Water Systems Files that usage of well UI#2 ended on October 12, 1964 (Holthaus, 2007). The last known usage before cleaning is an undocumented attempt to bring well UI#2 back on line during the early 1980's (Holthaus, 2007). The attempt failed to re-establish UI#2 as a production well. No records are filed indicating usage of UI#2 between 1964 and the early 80's.

1.2 Proposed Abandonment of UI2 Well

Well UI#2 remained unused for nearly 45 years. For a several-year period leading up to 2004, the University of Idaho discussed plans to extend Stadium Drive to State Highway 8, but to do so would have required the formal abandonment and sealing of well UI#2. The UI#2 pump house is directly in the way of the proposed road extension project (Figure 1.1).

1.2.1 Condition of Well UI#2 after University Video Log Assessment

In the summer of 2004, the University of Idaho hired Strom Electric of Troy, Idaho to pull the pump out of well UI#2. Golder Associates volunteered to video document the condition of the well at no cost in order to assess how to proceed with abandonment procedures. Jim Bailey who was with Golder Associates at the time was the hydrogeologist from the Redmond, WA office who handled the well video logging of well UI#2.

The video log showed that both the 16-inch and 12-inch casings were entirely coated with scale that had accumulated over the years. According to the final depth of the video log, approximately 150 feet of accumulated sediments had collected at the bottom of well UI#2 (Figure 1.2).

One interesting condition in well UI#2 prior to cleaning was that water was entering into the well from the Wanapum basalt through a hole in the casing. Water was entering at a location where no perforations existed according to the UI#2 well log. At a depth of 192 fbls, water containing suspended particles was seen flowing out of the well through a small hole in the casing. A thick coating of oxidized scale covered the inner casing of the well and made it difficult to identify whether water was exiting the well through the perforations in the casing.

Jim Osiensky, Dale Ralston, Larry Kirkland, and Mike Holthaus witnessed the borehole video logging performed by Jim Bailey in 2004 (Osiensky, 2007). Water flow in well UI#2 was considered to be moving vertically downward and into the sediments of the Vantage Equivalent interbed below the Wanapum basalt.

Larry Kirkland at the time of the borehole video logging was the Executive Director of the Palouse Basin Aquifer Committee (PBAC). PBAC is a committee composed of representatives from the cities of Moscow, Pullman, and Colfax, Washington State University and the University of Idaho, and Whitman County and Latah County whose goal is to manage and preserve water resources in the Palouse Basin. Larry Kirkland had proposed the idea of connecting two separate aquifer systems for recharging the Grande Ronde aquifer system.

The idea for using well UI#2 to recharge the aquifer systems of the basin came from Dr. Dale Ralston. Dale Ralston is an emeritus professor of hydrology at the University of Idaho, and is a private groundwater production well consultant. According to Ralston (2006), one feasible way to recharge the aquifer systems would be to connect the upper and lower aquifer systems in the Palouse Basin using passive drainage wells. The wells would allow water to drain from the Wanapum Aquifer System to the lower aquifer systems.

According to Kirkland (2006), the flow conditions observed in the borehole video log for well UI#2 were suitable for conducting an aquifer recharge feasibility study. The feasibility study was proposed to PBAC, and was funded beginning in the summer of 2005.

1.3 Statement of Problem

The condition of well UI#2 was evaluated for this study. The conditions within well UI#2 were modified during this investigation by cleaning the casing and removing accumulated sediments at the bottom of the well. This study was designed to delineate the hydraulic effects of the cleaning of well UI#2 on the local ground water conditions.

1.4 Purpose

The purpose of this thesis is to investigate borehole water movement within the University of Idaho Well #2 to provide a basis for the evaluation of hydraulic effects resulting from the cleaning of the well. Well UI#2 was cleaned to allow increased vertical drainage of ground water from the Wanapum basalt to the Vantage Equivalent interbed.

1.5 General Objective

The general objective of this project is to delineate the effects of well cleaning and well development on the groundwater flow systems in the vicinity of well UI#2.

1.5.1 Specific Objectives

The following are the specific objectives for this project:

1) Describe the geologic and hydrogeologic controls on the movement of ground water in the Moscow area.

2) Develop a conceptual hydrogeologic model of the ground water conditions near well UI#2.

3) Delineate the effects of well UI#2 cleaning on the local groundwater flow environment.

4) Attempt to quantify the rate of water flow within the UI#2 borehole after cleaning and development of the well UI#2.

1.6 Method of Study

This study began by collecting water chemistry samples from well UI#2 in July 2005. During the summer and through late fall, three monitoring well nests along Paradise Creek were constructed into the underlying sediments of Bovill. Existing wells completed into the Wanapum basalt and Vantage Equivalent interbed at the University of

Idaho Groundwater Field Laboratory (UIGFL) were monitored for this project. Paradise Creek surface water temperatures were monitored from October 2005 until March 2006. Ground water levels and ground water temperatures for the monitoring network were measured before, during and after cleaning of well UI#2. Water levels and temperatures were measured from January 2006 until March 2006. These data were analyzed to delineate the hydraulic effects of well UI#2 cleaning on the water resource systems of the area.

In February 2006, well UI#2 was cleaned and the well condition was documented by video logging. Based on the video well log for well UI#2 after cleaning, three different tracer tests were conducted to estimate the rate of water flowing downward in the borehole. The tracer tests were conducted between June and September 2006.

1.7 Previous Investigations

Several investigators have contributed important details about the geology and hydrogeology within the Pullman-Moscow Basin. This section will briefly describe certain details that are most important to this study. These details have aided in development of a conceptual hydrogeologic model to help illustrate how cleaning well UI#2 has affected the local groundwater environment.

An investigation by Li (1991) at the UIGFL evaluated the hydraulics of the fractured Lolo basalt flow of the Wanapum Formation. Multiple aquifer tests were conducted in the fractured basalt aquifer. Li concluded that monitoring wells at the UIGFL are completed into two separate fracture networks composed of an E-fracture (eastern portion of the UIGFL) and a W-fracture (western portion of the UIGFL). Under hydraulic testing, the pumping well completed in the E-fracture was shown to be hydraulically connected to Paradise Creek.

Pardo (1993) evaluated surface water and groundwater interaction between Paradise Creek and monitoring wells at the UIGFL. Water levels in the creek, in the sediments of Bovill, and in the upper portion of the Wanapum basalt were found to follow the same fluctuation patterns. The character of fluctuations was found to be dependent on distance from the creek and intensity and distribution of precipitation.

Kopp (1994) investigated the development of two University of Idaho production wells completed into sand layers in the upper one-third of the Vantage Equivalent interbed. Hydraulic testing of those wells affected local monitoring wells at the UIGFL completed into the Lolo flow of the Wanapum basalt and Vantage “equivalent” interbed. Results from testing yielded a combined transmissivity value of 2360 ft^2/day, and indicated the existence of a downward vertical gradient between the two units.

Provant (1995) investigated water levels measured in 74 wells for changes related to potential recharge events. Analysis of water levels indicted that the shallow aquifer (sediments of Bovill) and upper basalt aquifer (Wanapum Formation) have a rapid response to seasonal recharge. Provant hypothesized that two main mechanisms drove recharge in the basin: 1) infiltration through the Palouse Formation, 2) stream loss and basin-margin infiltration via paleo-channel pathways.

Larson (1997) used stable isotopes to test current hydrodynamic flow models that suggested a significant Holocene recharge rate (2 to 5 cm y^{-1}) to the upper (Wanapum) and lower (Grande Ronde) basalt aquifers. Results from this study showed that waters from the lower aquifer were statistically distinct from waters of other stratigraphic units.

These findings suggest that Grande Ronde water was not precipitated under current climate conditions and recharge rates are smaller than have been proposed.

1.8 Physiography

The "Palouse" is a region of eastern Washington, and northern Idaho defined by the fertile hills and prairies north of the Snake and Clearwater Rivers. Approximately 30 miles north from these rivers along the Washington and Idaho state border is the ground water basin called the Palouse Basin.

The region is a major wheat-producing agricultural area. The origin of the name Palouse is theorized as the name of the Palus Indian tribe. Accounts of various early spellings (Palus, Palloatpallah, Pelusha, ect.) were converted by French-Canadian fur traders to the more familiar French word *pelouse*, meaning "land with short and thick grass" (Phillips, 1971). Over time, the spelling changed to "Palouse".

1.8.1 Palouse Basin

Moscow, Idaho and Pullman, Washington are the two largest population centers most proximal to the project site within the Palouse Basin. The Palouse Basin as defined in this thesis is a ground water basin nearly surrounded by topographic highs except towards the southwest. Topographic highs are generally composed of crystalline rock (granite and/or metasediments) that forms the bedrock boundaries of the basin. In the basin valley areas, rolling hills of loess that have been incised by streams are common. No crystalline rocks are exposed to the west except in the Snake River Canyon approximately 20 miles to the southwest (Figure 1.3).

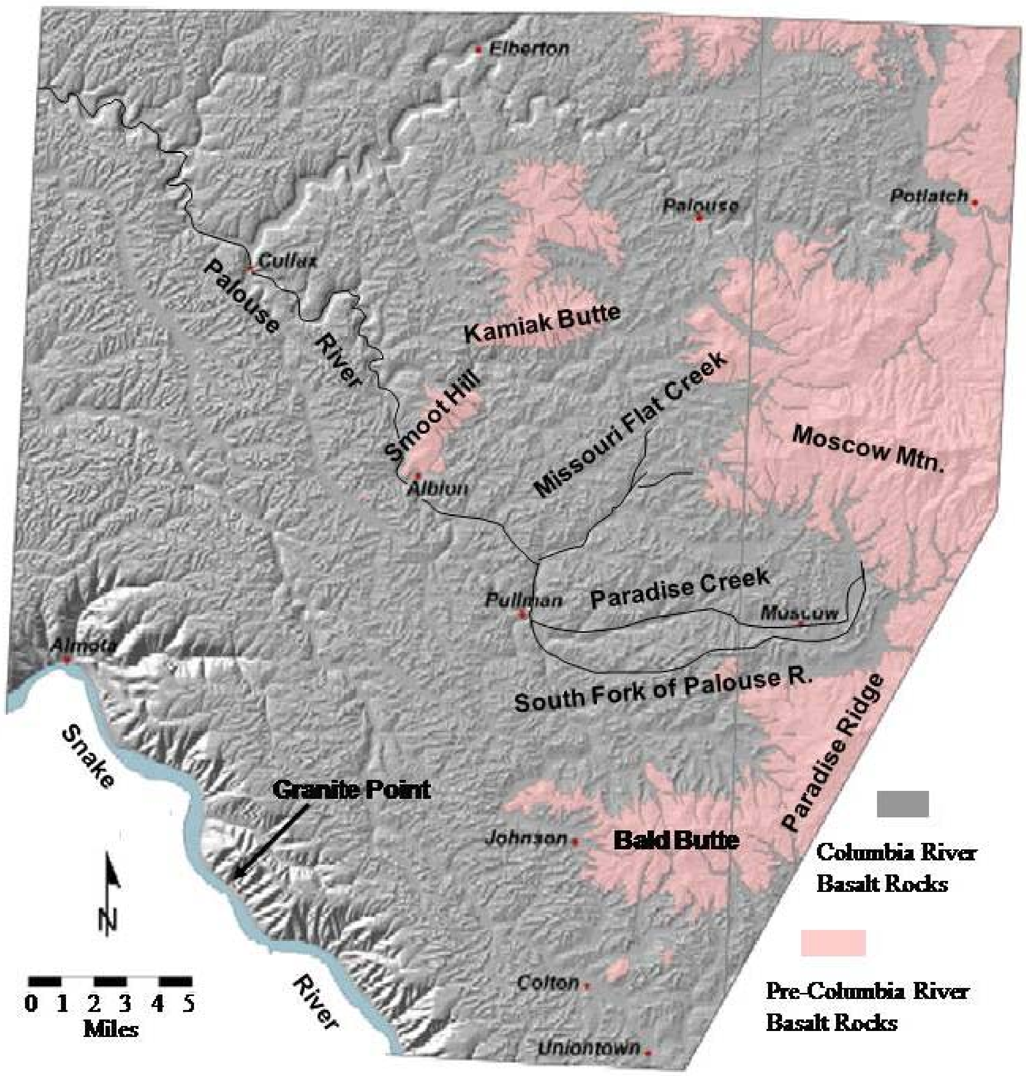

Figure 1. 3 Physiographic and Geologic Map of the Palouse Basin. The Snake River is located southwest of the basin. Granite Point is the only crystalline outcrop west of the Palouse Basin. (modified from Holom, 2006)

1.8.2 Pullman-Moscow Area

The Pullman-Moscow area is enclosed by ridges that form a horseshoe shaped topographic feature. The area is defined by Smoot Hill and Kamiak Butte to the north, Moscow Mountain and Paradise Ridge to the east, and Bald Butte to the south (Figure 1.3). The ridges are discontinuous on the limbs of the horseshoe where flood basalts have flowed over low ridge saddles and gaps between the topographic highs.

Drainages throughout the Pullman-Moscow area headwater on the surrounding topographic highs. The south fork of the Palouse River flows along the southern portion of the area, and Missouri Flat Creek flows along the northern portion of the area (Figure 1.3). Both streams headwater at approximately 3000 feet above mean sea level (famsl).

Paradise Creek flows directly through the city of Moscow, Idaho and into the south fork of the Palouse River in Pullman, Washington. The headwaters are located to the northeast of Moscow at approximately 4000 famsl. Paradise Creek has been re-routed at several locations in the city of Moscow area including immediately adjacent to well UI#2.

The seasonal flows in the basin streams are generally high from November through April and decrease significantly throughout the summer months. The stream stage height in these streams rises and falls rapidly during each precipitation event. This characteristic of stream behavior in the basin has caused flooding and annual property damage. In the spring of 1995, Paradise Creek flooded extensive portions of low-lying areas along the stream channel in Moscow and on University of Idaho campus.

The northern portion of the University of Idaho Campus proper is situated on the flood plain of Paradise Creek, which flows generally from east to west. Well UI#2 site is located on the western end of campus along Paradise Creek. At this location the stream flows through an under-roadway-tunnel beneath Paradise Creek St., then daylights and turns briefly north, and then west along Highway 8 (Figure 1.1).

The Pullman-Moscow area receives an average of 24 inches of precipitation annually; most of the precipitation occurs over the fall, winter, and spring months (October to May). The mean annual air temperature is 8.4ºC. Summers in the basin are warm and dry while winters are cold and wet. The average high temperature is 29.1ºC and the average low is –4.4ºC.

CHAPTER 2 HYDROGEOLOGY

This chapter describes the hydrogeology of the Palouse Basin. The geologic setting will provide the framework for how all the separate geologic units were emplaced in the basin. The geology of each unit is described in the present day regional and local setting. The regional geology is described in terms of the entire Palouse Basin (Figure 1.3) while the local geology is described within the Moscow area. Following the local geology is a description of the water resources as aquifer systems of the Pullman-Moscow area. Finally, a conceptual model of groundwater flow at UI#2 field site is presented.

2.1 Geologic Setting

The Palouse Basin is located on the eastern edge of the Columbia River Basalt Plateau. The basalt lava flows occurred from fissures located in southeastern Washington and northeastern Oregon (Swanson and others, 1980). The areal extents of the Miocene basalts range from portions of northwestern Idaho, south-central Washington, northeastern Oregon and the Washington coast (Figure 2.1).

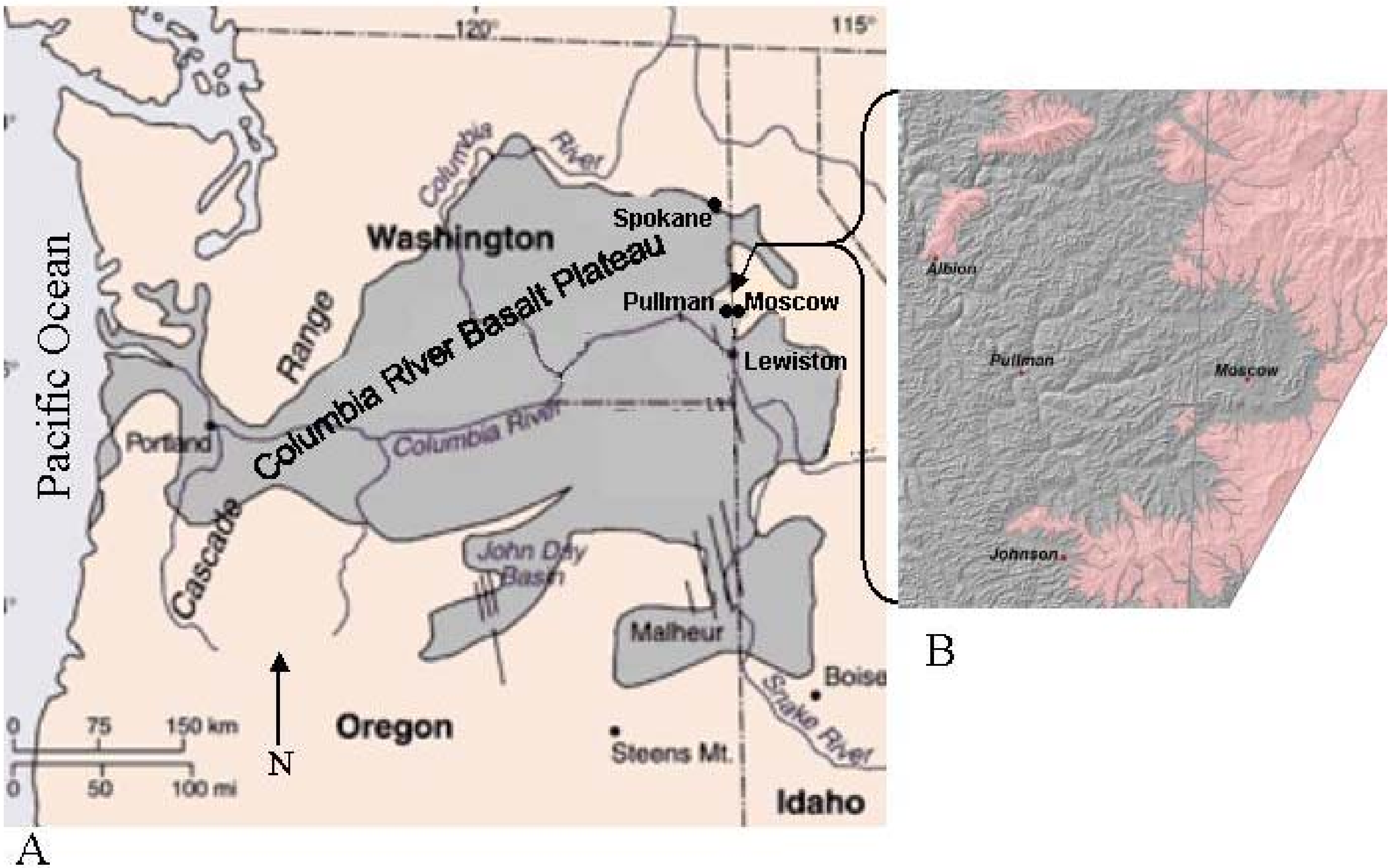

Figure 2. 1 Location of the study area along margin of Columbia River Basalt Plateau. A. Extents of the Columbia River Basalt Plateau in relation to the Pullman-Moscow area. B. Moscow ID is located 7 miles east of Pullman WA on the eastern margin of the Columbia River Plateau.

The Columbia River Basalt Plateau is comprised of basalt flows and interbedded sediments of the Columbia River Basalt Group (CRBG). The CRBG of the Palouse Basin consists of a succession of Miocene basalt flows from the southwest that submerged much of the pre-existing crystalline rock basement-complex topography. The pre-basalt topography is thought to have been steep with significant relief much like other areas of north-central Idaho. The entire Palouse Basin is believed to be underlain by a crystalline basement. A dendritic drainage pattern is believed to have been scoured into the basement rocks. The stream scoured channels are believed to contain sediments of the Latah Formation that are thought to be coarse sands, and gravels due to the high-energy fluvial environment. Sediments accumulated along the interface between basalt flows and crystalline basement highs after each basalt flow advanced into the area. Each basalt flow cooled to form uneven flow top and bottom surfaces containing sub-horizontal and vertical cooling fractures. The drainages scoured into the crystalline basement were damned and small lakes resulted as basalt flows advanced eastward. The lacustrine and fluvial environments were re-established during the next basalt flow advancement period. The lacustrine and fluvial sediments were covered forming sub-horizontal sediment interbeds. It is believed that these sediments draped over the interface between the crystalline basement and the terminus of successive basalt flows.

The uppermost basalt flow and associated sediments were covered by eolian windblown flood deposits forming the Palouse Formation. The dune shaped deposits of these sediments form the rolling topography known as the “Palouse”. Channels of present day streams have cut through the Palouse Formation in some areas.

2.2 Regional Geology

The regional geology of the Palouse Basin consists of several major geologic units. The following paragraphs summarize the characteristics of the rock units from oldest (bottom) to youngest (top).

2.2.1 Basement Rocks

The oldest rocks of the Palouse region are composed of Precambrian metasedimentary (metaseds) units of schist, gneiss, and quartzite. Outcrops of these rocks are present on most of the highest hills and ridges and follow a generally east-west trend throughout the eastern portion of the Palouse Basin. East of the Palouse Basin, these rocks grade into rocks of Belt Supergroup. Along the eastern perimeter of the basin buttes and hills of Precambrian and Cambrian metased rocks consist primarily of recrystallized quartz sands called quartzite (Bush et al., 1998b). The youngest pre-basalt rocks of the basin are Cretaceous in age and composed of undifferentiated intrusive and metamorphosed rocks of the Idaho Batholith (Bush et al., 1998b). These rock packages are referred to as the crystalline basement-complex that existed prior to emplacement of the CRBG and Palouse Formation.

2.2.2 Columbia River Basalt Group

The formations of the CRBG that reside in the Pullman-Moscow area are from bottom to top: Imnaha, Grande Ronde, Wanapum, Saddle Mountains, and Latah Formation (sediments). The basalt units and their associated sediment interbeds form the primary groundwater aquifer systems in the Palouse Basin. The Latah Formation sediments accumulated below, between and above the basalt flows of the CRBG. The

Imnaha Formation is the first basalt formation to inundate the pre-basalt crystalline basement topography within the Palouse Basin. The Imnaha makes up 5.5% of the CRBG by volume (Swanson, 1989). Above the last Imnaha flow is the Grande Ronde Formation. The Grande Ronde Formation makes up 87% of the CRBG by volume (Swanson et al., 1989). Outcrops of the Grande Ronde Formation occur along deeply incised river canyons that border the Palouse Basin.

A thick deposit of Latah Formation sediments above the last Grande Ronde Formation flow resides generally on the eastern portion of the Palouse Basin. This thick sedimentary interbed unit is considered to be "equivalent" to the Vantage Member of the Ellensburg Formation in central Washington. The Vantage "Equivalent" (herein after called the Vantage) and the Vantage Member exhibit similar stratigraphic sequences, and separate the Grande Ronde Formation from the Wanapum Formation in both locations. In most cases, the similar stratigraphy represents deposits associated with the reestablishment of an integrated drainage system on and across the basalt (Carson et al., 1987). On top of these sediments, the Wanapum Formation was emplaced.

The Wanapum Formation makes up 6% of the CRBG by volume (Swanson et el., 1989). Four members of the Wanapum Formation have been officially named: the Eckler Mountain, Frenchman Springs, Roza, and Priest Rapids. The Wanapum Formation generally crops out throughout the Palouse region on high canyon walls in the west and along stream channels and roadcuts in the east. The last basalt formation of the CRBG is the Saddle Mountains. The Saddle Mountains Formation makes up 1.5% of the CRBG (Swanson et al., 1989). However, the Saddle Mountains Formation exists locally only as small isolated flows. On the eastern margin of the Palouse Basin, Latah Formation sediments from exposed crystalline basement highs deposited the final unit of clay-silt and sands locally called the sediments of Bovill (Bush et al., 1998a).

2.2.3 Palouse Formation

The youngest geologic unit in the Palouse region is the Palouse Formation. The Palouse Formation loess is an eolian, silt-clay loam (Othberg and Breckenridge, 2001), which are deposits of eolian reworking (Busacca, 1991) of glacial outburst flood sediments periodically deposited (Bjornstad et al., 2001) over a 2-4 million year period from Pliocene through Pleistocene. The glacial slack water deposits were blown in from central Washington to form into the characteristic large dune shape hills of the Palouse region we see today (Williams and Allman, 1969). The formation covers a large portion of southeastern Washington and northeastern Idaho known as the "Palouse".

2.3 Local Geology

The local geology within the Moscow area consists of crystalline basement rocks, interbedded sediments and basalt flows within the CRBG, Latah Formation sediments, and Palouse Formation loess. The geologic units of Moscow, Idaho area are discussed from oldest to youngest in the following paragraphs. Figure 2.2 illustrates the general stratigraphic sequence of the geologic units in the Moscow area.

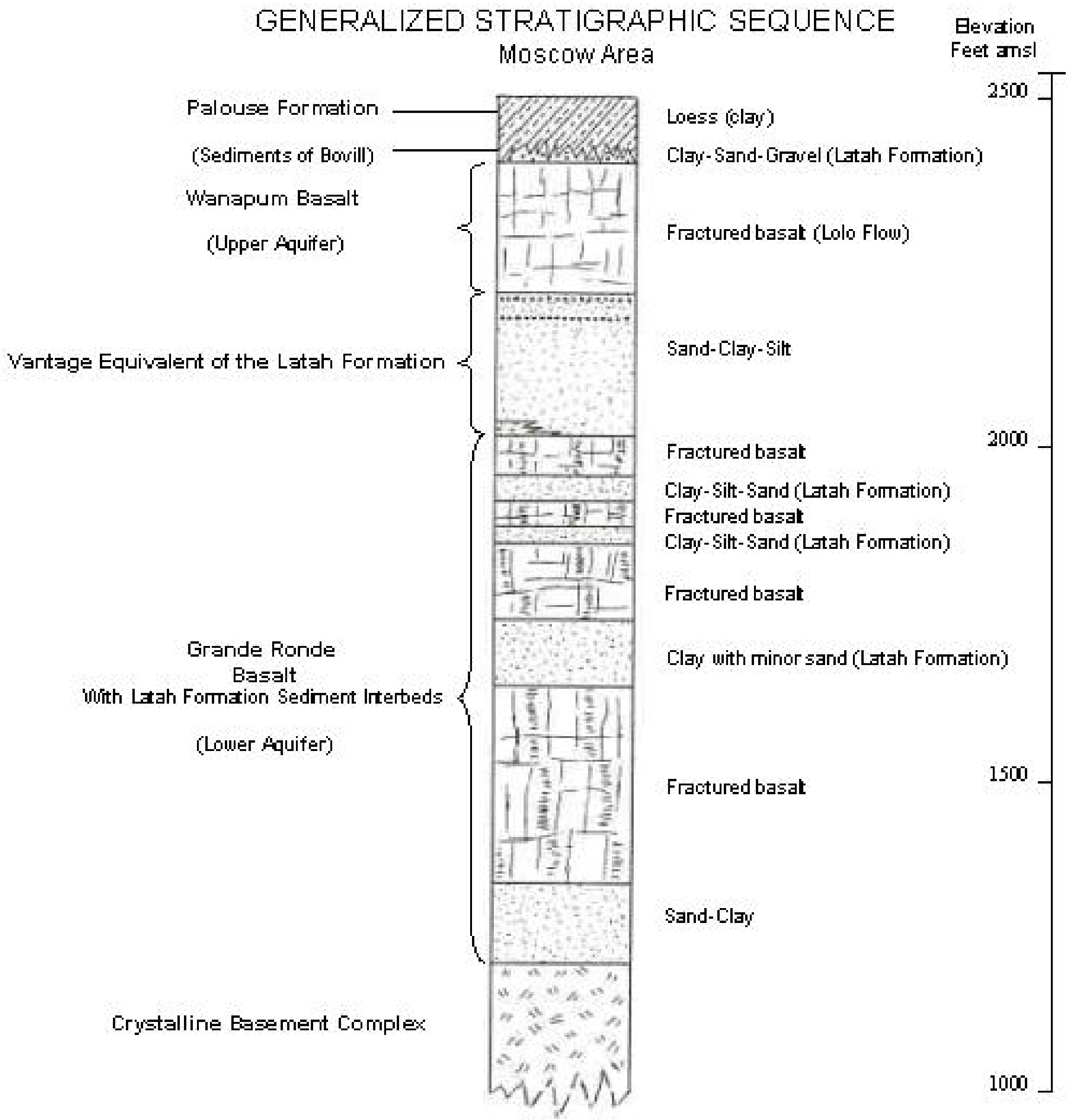

Figure 2. 2 Generalized stratigraphic sequence of the local Pullman-Moscow Basin. (Modified from Kopp, 1994)

Figure 2.3 is a plan view of the spatial distribution of the crystalline basement ridges and buttes surrounding the Moscow area.

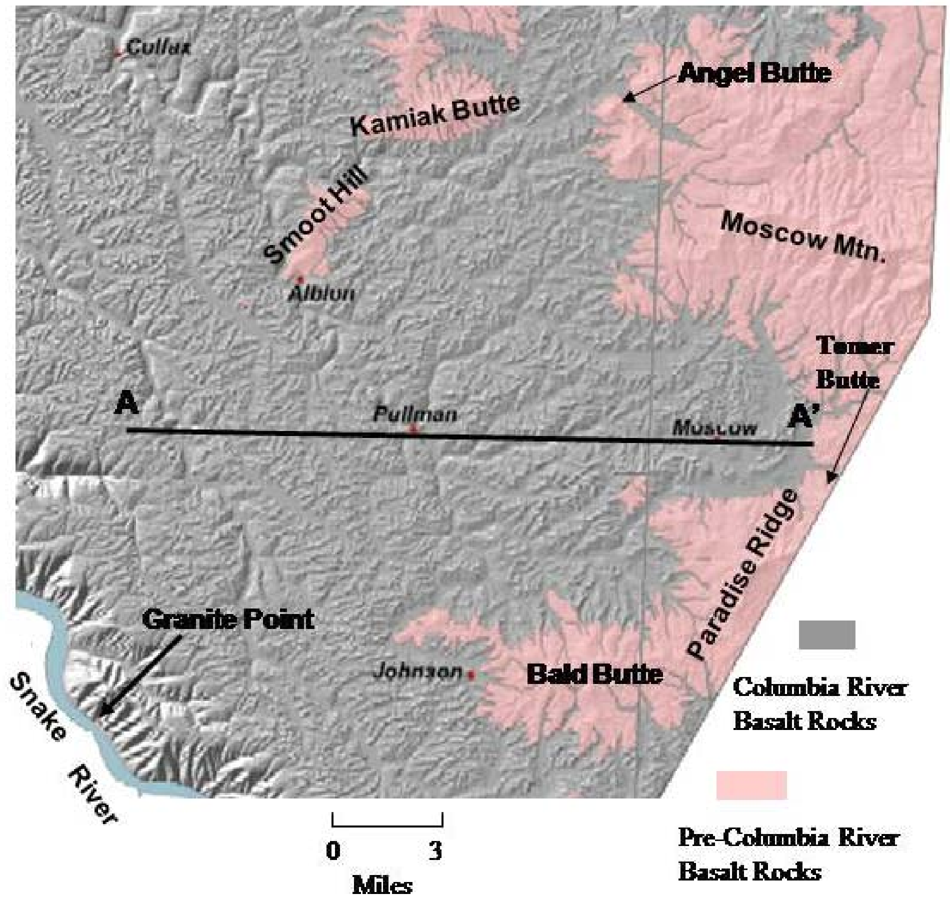

Figure 2. 3 Map of crystalline rock topographic highs surrounding Pullman-Moscow area. Plan view of the hills, ridges and buttes that form a horseshoe shape surrounding the local basin (Modified from Holom 2006). A-A' cross section is shown in Figure 2.4.

2.3.1 Basement Complex

The exposed basement complex surrounding Moscow, ID is composed of Precambrian and Cambrian metaseds, and Cretaceous undifferentiated metamorphosed and unmetamorphosed granitic rocks of the Idaho Batholith (Bush at el., 1998). Bald Butte and Paradise Ridge are composed of undifferentiated intrusive rocks of Cretaceous age along with Precambrian quartzite. Tomer Butte is composed of a package of Precambrian quartzite, schist, and gneiss rocks. North of Moscow is Moscow Mountain (Figure 2.3), which is the highest point, at 4989 famsl, in the local area, and is a part of the Cretaceous Idaho Batholith. Northwest of Moscow Mountain is Angel Butte, which is composed of the same Precambrian rock package as Tomer Butte. Kamiak Butte is composed of Precambrian undifferentiated argillite, siltite, and phyllite on the northern portion and Cambrian quartzite of Kamiak Butte on the southern segment (Bush and Garwood, 2005). Smoot Hill is a topographic high composed of Cambrian quartzite of Kamiak Butte. These crystalline basement highs are considered to form the local basin divides.

2.3.2 Igneous and Sedimentary Rock Units

The Wanapum and Grande Ronde Formations of the CRBG are the primary rock units in the Moscow area. The upper most formation that covers most of the Moscow area is loess of the Palouse Formation. The basalt units and their associated sediment interbeds form the primary groundwater aquifer systems in the Palouse Basin. Figure 2.4 illustrates the stratigraphic relationships between the basalt units across the Palouse Basin.

Geologic Cross Section of the Pullman-Moscow area, Idaho – Washington

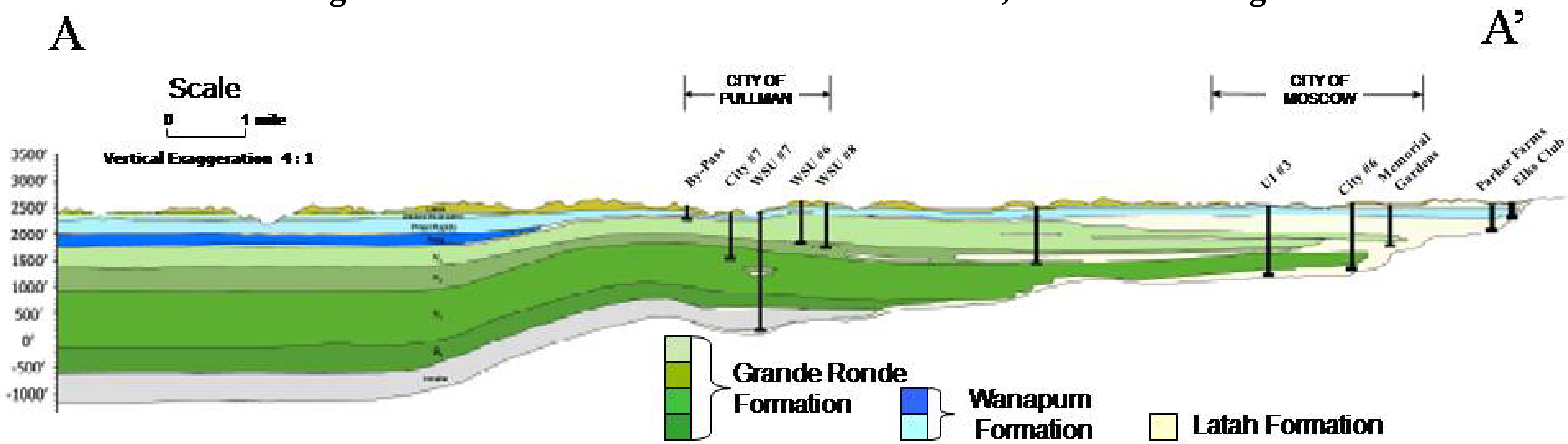

Figure 2. 4 East to West Cross section of across the Moscow-Pullman area(from Bush and Garwood, 2005). Color scale represents multiple members of a formation. Location of the cross-section A-A' is shown on Figure 2.3.

2.3.2.1 Grande Ronde Formation (basalt)

The basalt flows of the Grande Ronde Formation constitute the lowermost basalt formation in the Moscow area. Thickness of the Grande Ronde varies spatially and individual flows vary in thickness from a few feet to nearly 200 feet (Foxworthy and Washburn, 1963). Sediment interbeds of the Latah Formation exist between some of the basalt flows. The thickness of the interbeds varies spatially based on proximity to the sediment source and the location of the terminus of the basalt flows.

The Grande Ronde is nearly 800ft thick below Moscow. Almost 2000ft of Grande Ronde basalt exist under the Pullman area (Owsley, 2003). This thickening to the west is a result of the westward sloping crystalline rock topography that existed prior to emplacement of the successive basalt flows.

Individual flows of the Grande Ronde Formation were identified by using paleomagnetic, geochemical, and stratigraphic sequencing; these techniques have identified 17 separate Grande Ronde flows in the Palouse Basin (Foxworthy and Washburn, 1963).

2.3.2.2 Wanapum Formation (basalt)

The Wanapum Formation is areally extensive throughout the basin and crops out along the crystalline basement margins, stream channels, and is exposed in areas of road cuts, and quarries.

The Wanapum Formation is represented by the Lolo flow of the Priest Rapids Member. The Rosa Member is present to the west of Pullman, but does not extend into Moscow (Figure 2.4).

Exposures of vertical cooling fractures in the Lolo flow are located at quarries along Washington State Highway 270 between Moscow and Pullman (Figure 2.5).

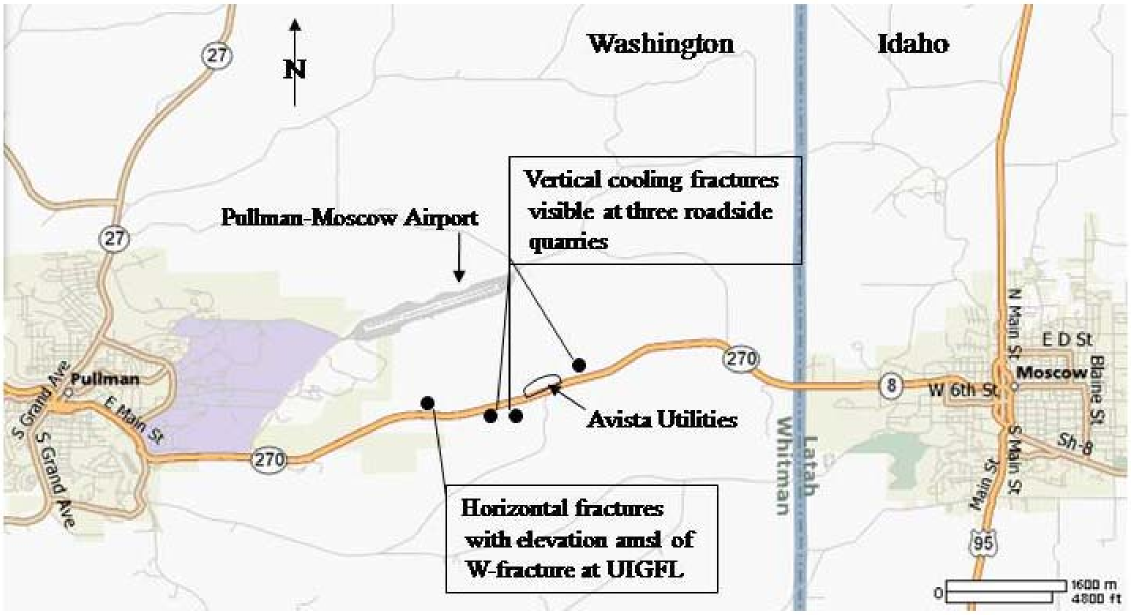

Figure 2. 5 Map locations of outcropped basalt features along Washington State Highway 270.

Vertical cooling fractures generally trend north-south (Bush, 2006). Several continuous vertical cooling fractures approximately 100 feet in length are exposed. These cooling fractures extend through the entire thickness of the basalt flow. It is believed that the cooling fractures are distributed throughout the Lolo flow and exist under Moscow (Bush, 2006).

Additional features of the Lolo flow were described by Li (1991) as two types of interflow structures based on observations from basalt outcrops at quarries along Washington State Highway 270. The features of these structures included: 1) thick columnar sections with alternating entablature and colonnade in the lower section and hackly entablature in the upper section; and 2) dense massive dark-gray basalt. The upper one third of the Lolo flow contains an oxidized zone with large frothy blocks and abundant sub-horizontal conchoidal fractures. Similar features of the Lolo flow were identified by (Kopp, 1994) from drill hole cuttings for University of Idaho Wells #5, #6, and #7 located in the University of Idaho Aquaculture Research Laboratory (UIAFL) (Figure 1.1).

2.3.2.3 Latah Formation (sediments)

Two sediment formations exist in the Moscow area. The oldest of the formations is the Latah Formation and the youngest is the Palouse Formation. The Latah Formation has informally been divided into three separate members based on the spatial distribution of the sediments. The three units from oldest to youngest are the sediments of Moscow, the Vantage, and the sediments of Bovill (Bush and Garwood, 2003) (Figure 1.1).

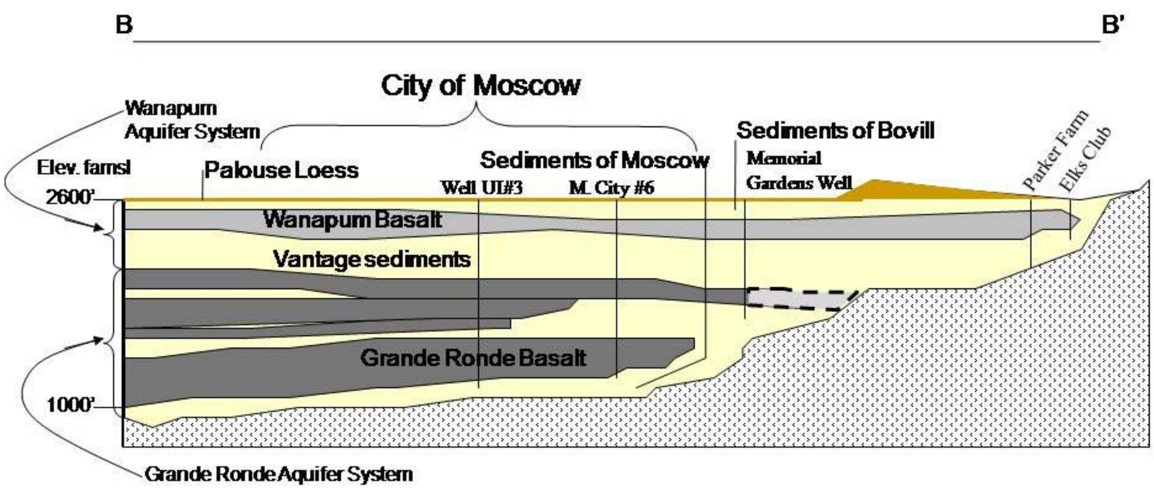

Figure 2. 6 Vertical distribution of Latah sediments about basalt units underlying Moscow, ID. Location of cross section B-B' is shown on Figure 1.1. Well logs from UI, City of Moscow, and private wells were used to construct this cross section.

The first stratigraphic unit in the subsurface above the crystalline basement is the sediments of Moscow. Several discontinuous layers of clay, silt, and sand exist under Moscow. Two major interbed units between Grande Ronde basalt flows were correlated between Moscow City wells trending east-west, these interbeds are up to 100 feet thick

(Cavin, 1964; Lin, 1967). These interbed units thin to less than a few feet westward toward Pullman, WA (Brown, 1976a).

The Vantage is a sediment layer that separates the uppermost Grande Ronde basalt flow from the lowermost flow of the Wanapum Formation (Figure 2.6). The thickness of the sediments ranges from over 300 feet beneath Moscow to less than 20 feet near Pullman. The Vantage sediments consist generally of interlayered sand, clay, and silt. Figure 2.7 is a stratigraphic column from the drilling log of well UI#2. Well UI#2 penetrates approximately 170 feet into the Vantage sediments.

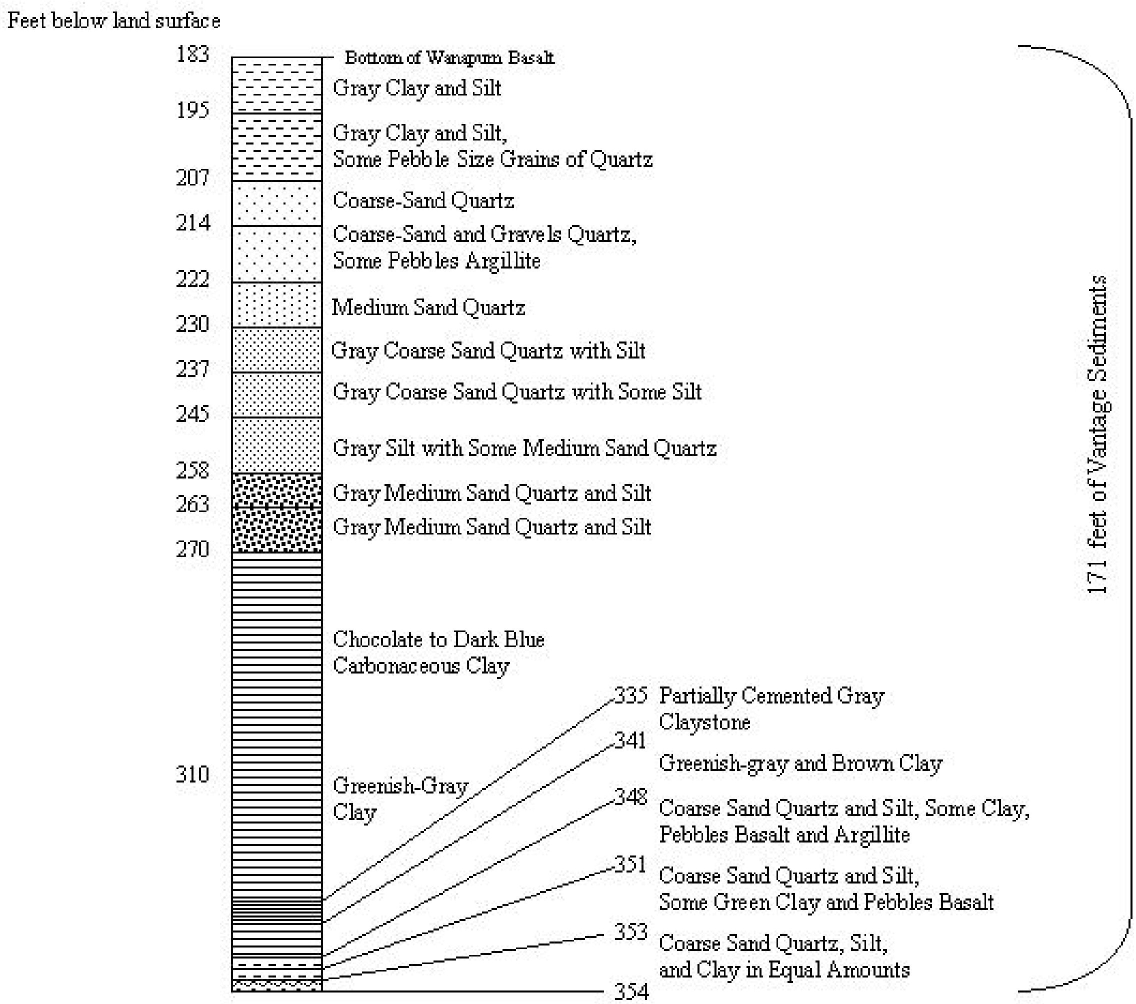

Figure 2. 7 Stratigraphy of Vantage sediments at well UI#2.

At the top of the column in Figure 2.7, 24 feet of clay and silt grades into a small percentage of sand size quartz grains immediately below the Wanapum/Vantage contact followed by 63 feet of quartz sand. The sands of this layer are poorly sorted with an increase of clay content towards the bottom and the coarse grains of quartz and feldspar are angular with only slightly rounded edges (Cavin, 1964).

The youngest unit of the Latah Formation is the sediments of Bovill (Figure 2.8).

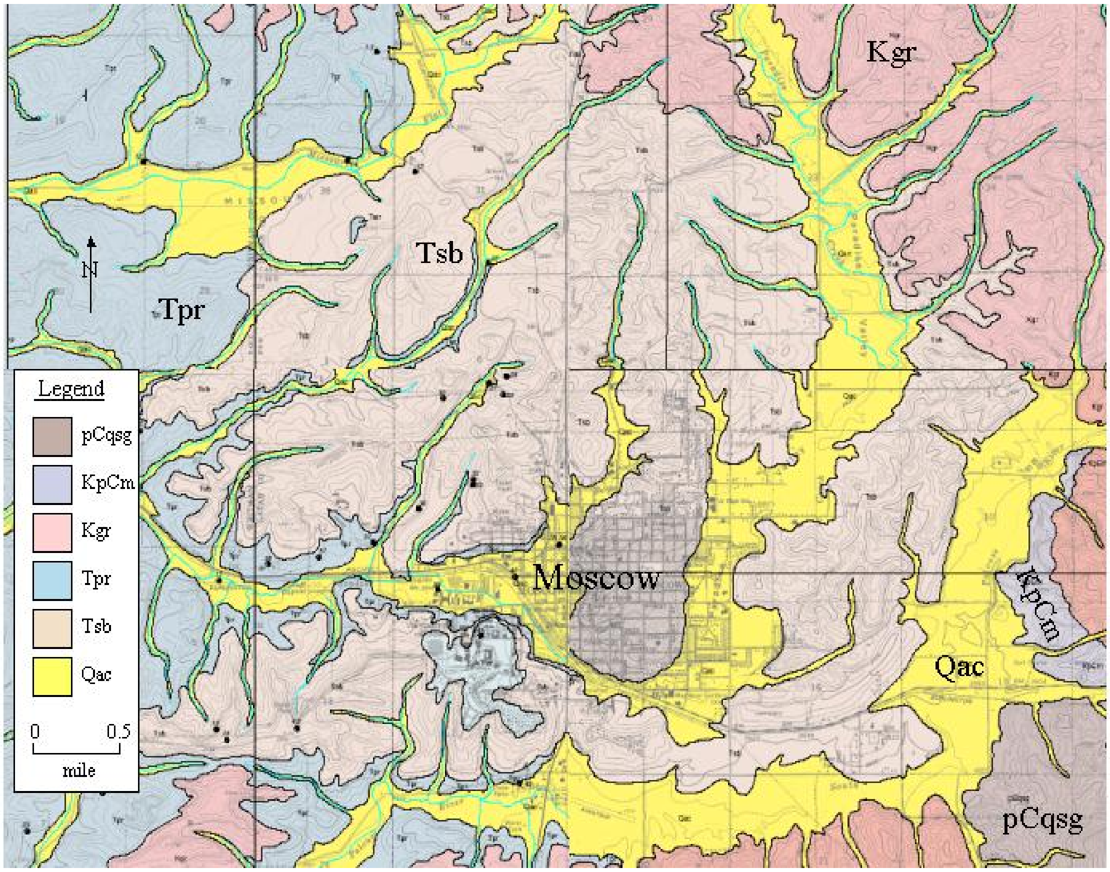

Figure 2. 8 Surficial geologic map for the local Moscow area. This map was generated from parts of four separate quadrangles: Viola (Bush et al., 1998b), Robinson Park (Bush et al., 1998), Moscow East (Bush et al., 2000), and Moscow West (Bush et al., 1998a).

The sediments of Bovill are only located in the Moscow area and overlie the Lolo flow of the Priest Rapids Member and the prebasalt rocks in area. The unit ranges in thickness from zero to about 200 feet with sands and gravels poorly sorted in a clay matrix (Bush and Provant, 1998b). Another sorted assemblage that is common for the sediments of Bovill has poorly rounded quartz and basalt granules and pebbles in a matrix of silt and clay (Bush and Provant, 1998b). The sediments along the eastern margin of the sediments of Bovill member consist of an upward-fining sequence of gravel or sand to clay. A sequence of minor silt overlain by thick clay units is common westward away from the source area (Bush and Provant, 1998b). The sediments of Bovill have several origins ranging from in situ weathered granite to shallow lacustrine deposits. However, most of these sediments are thought to have been deposited as fluvial deposits. Deposition was primarily caused by emplacement of the Lolo basalt that created a raised base level, which in turn caused the deposition of clays, quartz sand, and minor gravel from streams eroding nearby exposures of weathered prebasalt rocks (Bush at el., 2000).

2.3.2.4 Palouse Formation

Loess of the Palouse Formation varies in thickness from zero within the channel of Paradise Creek to 75 feet near wells UI 5, 6, and 7. Within the flood plain of Paradise Creek the loess may have been locally reworked and mixed with the sediments of Bovill (Osiensky, 2007).

2.4 Local Ground Water Resources

Most of the geologic units in the Pullman-Moscow area are, to some degree, water bearing. Two main aquifer systems have been delineated. The first is the lower system called the Grande Ronde aquifer system. The second is the upper system called the Wanapum aquifer system. The upper and lower aquifer systems are the primary municipal water resource systems in the Palouse Basin. The basement complex and Palouse Formation aquifer systems are used for domestic water supplies only.

2.4.1 Basement Complex Aquifer System

The basement complex rocks that surround the Pullman and Moscow area receive approximately 20 to 40 inches of precipitation annually. Some of the precipitation that falls on these units infiltrates and ultimately recharges the aquifer system. The amount of recharge is highly dependent upon seasonal snow accumulation and rate of snow melting.

Area residents are concerned in drier years because some domestic wells have gone dry by the end of the five-month dry season due to decline of the water table.

Wells in the basement complex rocks produce small amounts of potable water, but not enough for municipal supplies. Wells within the Palouse Basin completed into these rocks have yields between 0.5 and 60 gpm. Pumping rates typically decline towards the end of the dry season due to the falling water tables.

2.4.2 Grande Ronde Aquifer System

The Grande Ronde is currently the most heavily utilized aquifer system in the basin. Municipal wells completed into the Grande Ronde Formation in Moscow can produce over 2000 gallons per minute (gpm) (Smoot and Ralston, 1989). Production wells WSU #7 and #8 located on the campus of Washington State University, WA, produce up to 2500 gpm. The groundwater pumping in the Grande Ronde aquifer system in Moscow has not been found to affect the Wanapum aquifer system because approximately 130 feet of clay separates the two aquifer systems.

2.4.3 Wanapum Aquifer System

Locally, the Wanapum aquifer system is composed of the sediments of Bovill, Lolo basalt and Vantage sediments (Figure 2.6). Well drillers in the Moscow area have commonly completed wells with screened intervals in both the Wanapum basalt and Vantage sediments. Wells pumping water from both geologic units potentially are capable of producing water for municipal use. The city of Moscow and the University of Idaho have production wells completed in this fashion. Moscow well #2 has a maximum pumping capacity of 1150 gpm while the Moscow Cemetery well had a pumping capacity of 700 gpm until the well was decommissioned in 1990 due to sand invasion (Smith, 2007). The University of Idaho well #2 had a capacity to pump 500 gpm in 1958,

Not all wells completed in the Wanapum Aquifer System produce hundreds of gallons per minute. The UIARL well UI#5 has a sustained pumping yield of 50 to 70 gpm. The UIARL has two additional wells UI#6 and UI#7, which are completed into the Vantage sediments only and have pumping capacities of 75 and 80 gpm, respectively. As of 2006, UI#6 is the only on-line pumping well at the UIARL (Williams, 2007). Wells that derive ground water solely from the Lolo basalt can produce up to 300 gpm; however, well yields typically are less than 100 gpm. The Appaloosa Horse Club (AHC) well is completed in the lower portion of the Lolo basalt flow and has a pumping rate of 100 gpm.

2.4.4 Palouse Formation Aquifer System

The Palouse Formation blankets nearly the entire Moscow area (Figure 2.2). The thickness ranges from zero to 300 feet.

The Palouse Formation is recharged primarily by areally distributed precipitation that infiltrates. Throughout the Palouse Formation perched water tables are common. Water wells completed into the Palouse Formation can produce up to 30 gpm. These quantities are sufficient only for domestic use and livestock.

2.5 Conceptual Model of Groundwater Flow at the Well UI#2 Field Site

The ground water flow conditions near well UI#2 changed over time due to cleaning activities conducted in the well in February 2006. The ground water flow conditions that are believed to have existed prior to well cleaning, and those conditions that are believed to exist currently (2007) are described conceptually in the following sections.

2.5.1 Hydrogeologic Conceptual Model Before Cleaning

The local groundwater flow environment was evaluated based on water level data collected before cleaning activities began in well UI#2. The data were collected for existing monitoring wells at the UIGFL, and for well UI#2. No other monitoring wells exist between the two sites and so the hydrogeology was interpolated based on available data. Figure 2.9 is a diagram of the conceptual groundwater flow model of the conditions believed to exist before cleaning activities began in well UI#2.

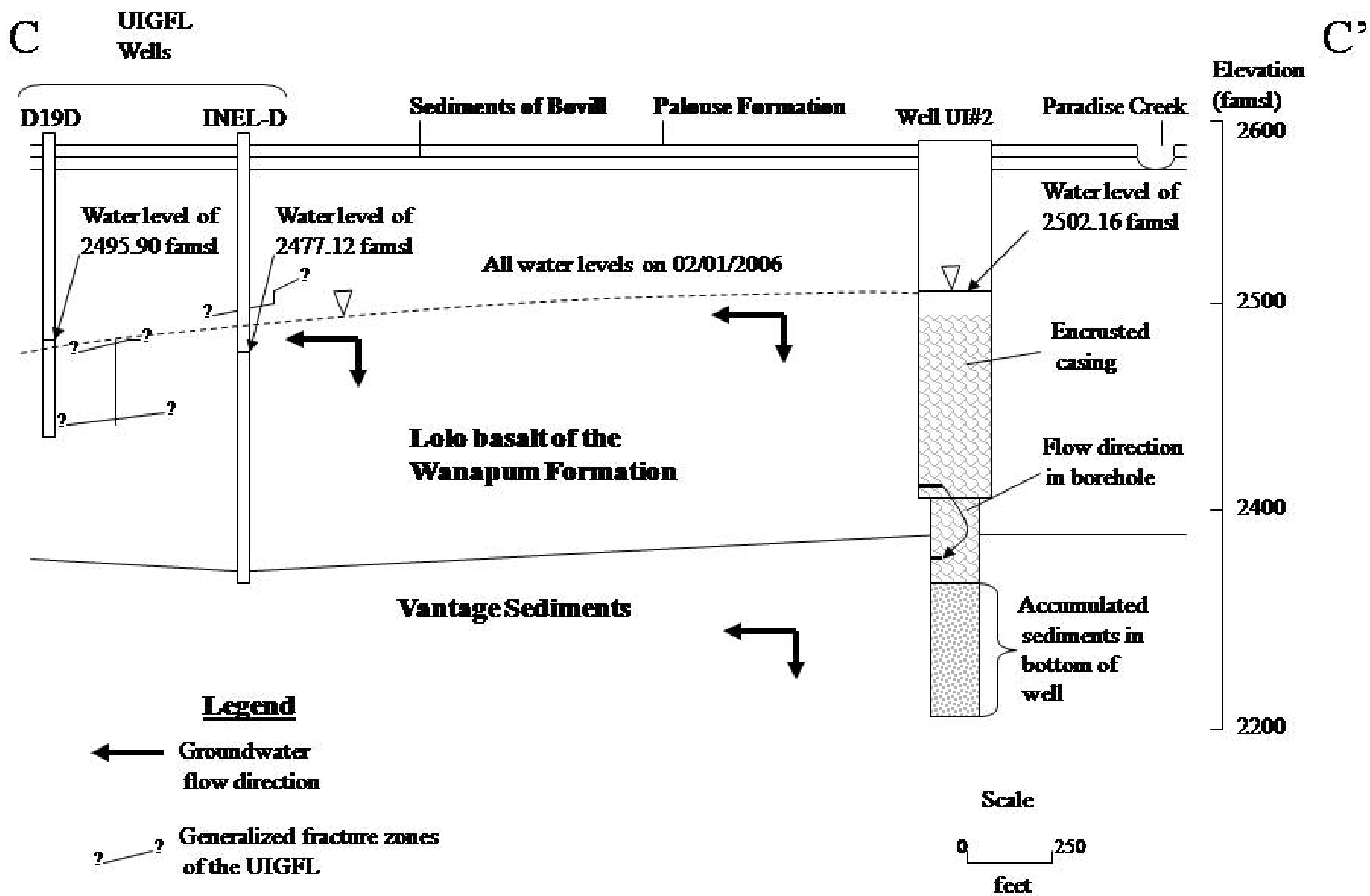

Figure 2. 9 Conceptual groundwater flow model before cleaning well UI#2. The model represents the groundwater flow between well UI#2 and UIGFL wells prior to cleaning well UI#2 in February, 2006. The general horizontal flow direction was from UI#2 toward UIGFL. A vertical downward gradient of 0.3 also existed between the Lolo flow and the Vantage sediments based on water levels measured in INEL-D and D19D.

The horizontal flow direction in the Lolo basalt and Vantage sediments was westward from well UI#2 toward the UIGFL prior to well cleaning. The horizontal direction was based on higher water level elevations that existed in well UI#2 compared with water level elevations in the UIGFL monitoring wells. However, groundwater also was moving vertically downward at both sites. At the UI#2 site, flow in the well was moving vertically downward based on evidence from the 2004 video log. At the UIGFL, water levels in monitoring wells completed at different depths (i.e. INEL-D and D19D) exhibited decreasing water level elevations with depth between the Lolo basalt and the Vantage sediments.

The greatest unknown about the hydraulic continuity between UI#2 and the UIGFL sites is the spatial distribution of fractures throughout the Lolo basalt flow. Bush (2006) suggested that the sub-horizontal basalt fractures that discharge groundwater at road-cut locations along HW8 may be the stratigraphic equivalent of the E-fracture network delineated by Li (1991) (Figure 2.5). The areal extent of the E-fracture may likely compliment the W-fracture and exist between the two sites. Compartmentalization in the Lolo flow suggested by Badon (2007) may also play a role in the degree of hydraulic continuity detected between well UI#2 and local monitoring wells. Unidentified basalt structures may produce groundwater flow boundaries, which may have influenced the behavior of monitored water levels after cleaning activities began.

CHAPTER 3 METHODOLOGY

3.1 Introduction

The methods described in this chapter are based on the hydrogeologic conceptual model of the ground water flow conditions that existed prior to cleaning activities in well UI#2. Water levels were monitored for changes in all geologic units of the Wanapum aquifer system. Existing local monitoring wells were incorporated into the monitoring plan along with monitoring wells that were completed specifically for this project.

Warm water tracer tests were conducted in well UI#2 after cleaning activities were completed. These preliminary tests were designed to help characterize the circulation environment within well UI#2 borehole.

3.2 Design and Implementation of Monitoring Program

A monitoring plan was designed to collect data prior to, during and after cleaning of well UI#2. The goal of the monitoring was to delineate changes that occurred due to cleaning and development of well UI#2. The aquifer units expected to be affected by cleaning were the sediments of Bovill, Lolo flow, and the Vantage sediments. The monitoring program was designed with four main objectives:

1. Monitor changes that occur within well UI#2 due to cleaning activities.
2. Construct and develop monitoring wells in the sediments of Bovill along Paradise Creek for monitoring groundwater and surface water interactions.
3. Establish a network of existing wells to monitor water levels and temperatures in the Lolo flow of the Wanapum Formation, and the Latah Formation (Vantage sediments).
4. Monitor Paradise Creek stage height and water temperatures.

3.2.1 Measurement Protocol

Electronic data loggers were used for collection of water level data and temperature data. Solinst model 3001 Leveloggers^{TM} with three different pressure ratings (F15/M5, F30/M10, and F100/M30) were used in this study. Monitoring was divided into three separate periods. Cleaning Period 1 consisted of data collected prior to well cleaning. Cleaning Period 2 consisted of data collected during well cleaning. Cleaning Period 3 consisted of data collected after well cleaning.

Cleaning Period 1 monitoring started on January 16, 2006. Data loggers were set in Paradise Creek and in wells T16D and INEL-D at the UIGFL to record hourly. An existing data logger in well UI#2 was used to record water levels before this project started. The data logger in well UI#2 was downloaded and reset for this project. Each data logger in the monitoring network was set approximately five feet below the static water level in each well. A hand measurement of the depth to water was taken at the beginning and end of each data logger data set. The depth to water is the distance from the top of the wellhead to static water level. Depth to water measurements were used to calculate the water level elevation changes over time in each well. The water level elevations are expressed in feet above mean sea level (famsl).

Cleaning Period 2 monitoring started on February 8, 2006 and extended to February 22, 2006. A one-minute sampling frequency was used during Cleaning Period 2 which included the time period during well cleaning. Cleaning Period 3 monitoring started on February 22, 2006 and continued to May 2, 2006. Data were collected on a one-minute sampling frequency from February 1, 2006 to March 3, 2006. From January 21, 2006 to May 31, 2006 data were collected on a one-hour (60-minute) sampling frequency. All data collected during this project are on a CD ROM attached to the rear cover.

Barometric pressure data were used to correct water level data collected in monitoring wells. Barometric pressure data for the Pullman-Moscow airport (PMA) were obtained from the National Weather Service, Spokane, WA. Office. The airport is located approximately four miles to the west of well UI#2. The water level data were evaluated to determine whether they were affected by barometric pressure changes. The PMA barometric pressure record was downloaded for the year 2006 to be used for the water level corrections (Figure 3.1).

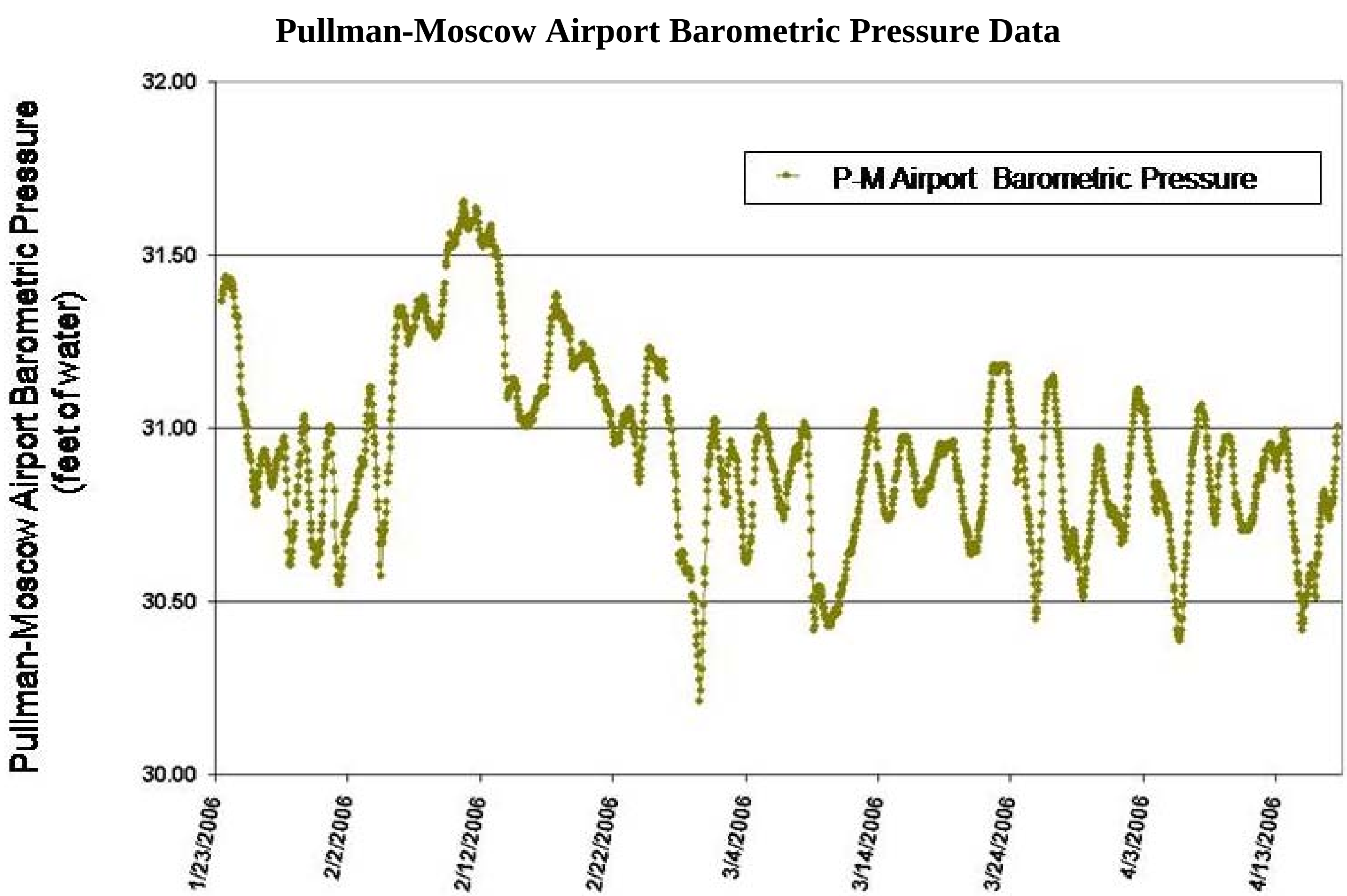

Figure 3. 1 Plot of barometric pressure (normalized to mean sea level) for the period 01/23/2006 to 03/14/2006.

Barometric Earth Tide Correction software (BETCO™) has the ability to filter out the effects of barometric pressure variations and earth tides on water level data. BETCO requires water levels and barometric pressure readings for the same time frequency and over the same time period, but earth tide data are optional. An Excel spreadsheet with columns for time, water level, and barometric pressure can be imported into BETCO for correcting any data set that covers a time period of at least seven days. The software removes the effects of barometric pressure variations and earth tides from water level observations using regression deconvolution. This procedure can be applied to both confined and unconfined aquifer systems. The software accounts for the lagged responses associated with barometric pressure and earth tide changes. The corrected data can be saved on the original imported Excel spreadsheet for comparison.

Barometric pressure data for the PMA and water level data for the Paradise Creek monitoring wells and UIGFL monitoring wells were evaluate with the BETCO™ software. Any additional water level data that aided in this investigation were also corrected by BETCO™ software (Attached CD ROM).

3.2.2 Well UI#2 Data Collection

University of Idaho Well #2 was monitored before and after cleaning. Well UI#2 is completed through the Wanapum basalt and into the Vantage sediments. Based on the well log, the well originally was slotted in both the Wanapum basalt and the Vantage sediments. Information from the UI#2 well log shows that perforations existed originally over the same intervals on both the outside and inside casings (Figure 3.2).

Well Log for University of Idaho Well #2

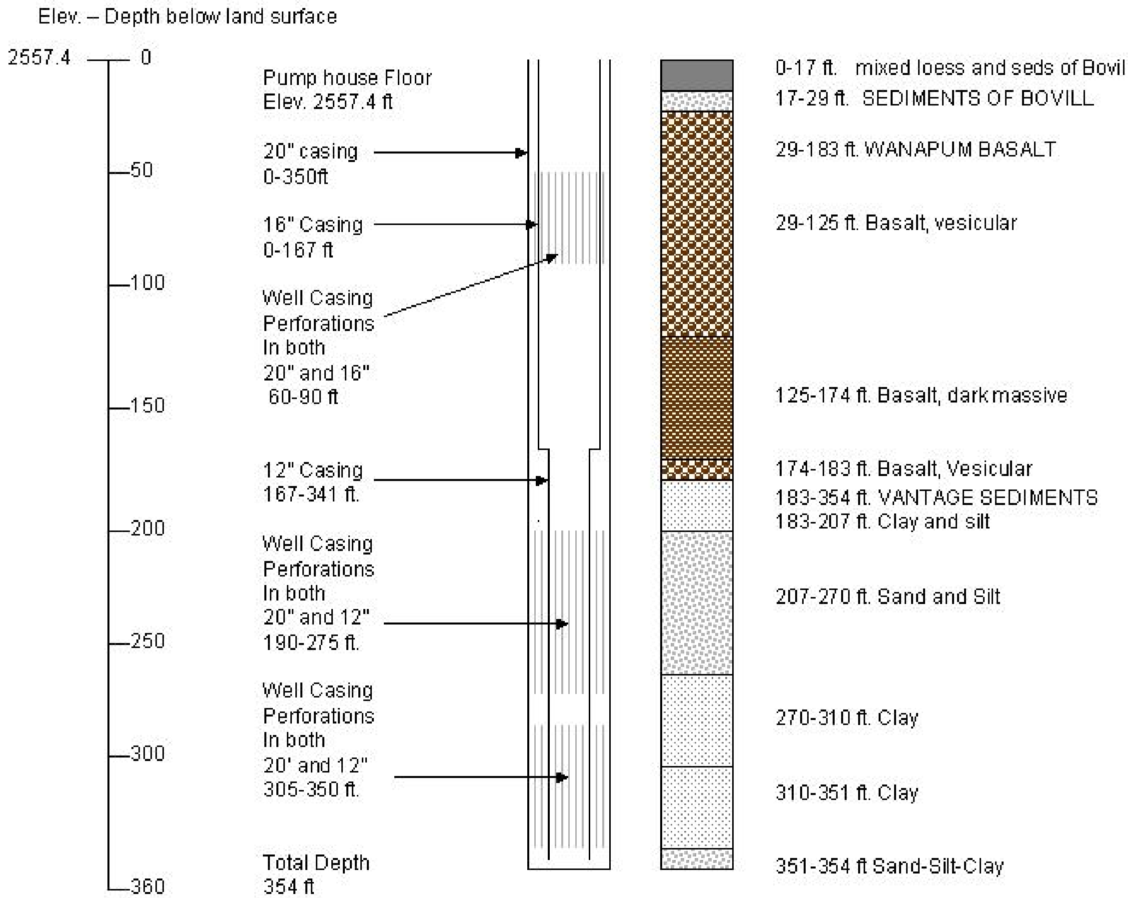

Figure 3. 2 Well UI#2 well log and construction details. This well log for UI#2 is based on notes from the only well log schematic that is known to exist.

Monitoring of water levels in well UI#2 was not possible during cleaning activities.

Groundwater samples were collected in well UI#2 prior to well cleaning to evaluate the water quality. The samples were collected by setting a submersible pump thirty feet below static water level in well UI#2. Samples were collected after pumping for 15 minutes. Eleven 125ml polyethylene sample bottles were filled with water pumped from well UI#2. The samples were placed on ice in a cooler, and transported to Anatek Labs, Inc. in Moscow Idaho. Anatek Labs, Inc. is a private, certified analytical laboratory that provides environmental, agricultural, residential, and industrial testing services. The complete list of Environmental Protection Agency (EPA) analysis methods and the associated percent recovery and acceptance range are located on attached CD ROM.

Cleaning and development of well UI#2 started on February 10, 2006. Holt Drilling Co. from Puyallup, WA. was contracted by PBAC to do the cleaning. The scheduled tasks for cleaning well UI#2 were as follows:

1. Bail out sediments accumulated at the bottom of well UI#2.
2. Brush well UI#2 casing to the depth where sediments where removed.
3. Swab casing and bail materials accumulated due to brushing.
4. Video inspect well to evaluate and document the final borehole conditions.

Holt Drilling Co. arrived at the UI#2 pump house at approximately 07:30 hours on 02/10/2006. Set up took approximately 30 minutes; this included positioning of the boom and cable rigging, and establishing a staging area for various pieces of equipment that would be needed during subsequent well cleaning and development activities (Figure 3.3).

Figure 3. 3 Photo of Holt Drilling Co. set up on UI#2 well house for cleaning activities.

Before cleaning could begin the roof cap needed to be removed along with the wellhead cover so the cleaning equipment could be lowered into the well. After the wellhead cover was removed, the 20” casing could be observed (Figure 3.4).

Figure 3. 4 Photo of well UI#2 casings. 20” casing is exposed above concrete pad. The inside 16” casing (not visible) is approximately 12” below floor level.

The data logger that was recording water levels in well UI#2 was removed in preparation of well UI#2 cleaning. Unfortunately, this data logger malfunctioned, and the water level data were unable to be recovered. The last background water level measurement in well UI#2 was on February 2, 2006 during removal of the data logger prior to cleaning. The depth to water on February 2, 2006 at 09:00 hours was 54.75 fbls (2502.65 famsl). Water levels in well UI#2 were measured by hand periodically with an e-tape while cleaning was in progress. Because the cleaning activities in well UI#2 involved heavy equipment, no data logger could be safely placed in the well.

The bailer was first lowered into well UI#2 at 08:15 hours on February 10, 2006. Bailing removed the sediments that had accumulated at the bottom of the well over a period of 40 years. The driller noted that initially the bailer could be lowered to 200 fbls. This was approximately 50 feet lower than the video camera was lowered in July 2004. After bailing for three hours, the bottom of the well was at 258 fbls. When bailing ended for the day at 11:00 hours, the depth to water was 59.92 fbls (2497.48 amsl). Cleaning activities were then terminated for the day at 12:00 hours. February 11 and Sunday February 12 (Saturday and Sunday, respectively) were off days.

Brushing and bailing activities commenced again on February 13, 2006. The sediments that were bailed from well UI#2 consisted of flakes of black magnesium scale, 1/8" diameter grains of consolidated green clay, 1/16"-3/4" grains of basalt, and a range of fine to medium size quartz grains. The basalt grains are from the Wanapum Formation and the quartz grains and clays are from the Vantage sediments.

During the cleaning process, the bailer became hung up in the well. It is not known what depth the bailer was hung up, but the manner in which it was yanked free definitely ripped the brittle casing during the process. The driller was able to work the bailer free, but the top assembly had broken at a weld. Because of the broken bailer, cleaning for the day ended at approximately 17:00 hours.

Brushing of the 12" and 16" casing was completed on February 14, 2006. Well UI#2 was bailed to a final depth of 342 fbls. Bailing ended at this depth because the budget was exhausted and work ended pre-maturely.

Several samples of the material bailed from well UI#2 were collected. Two of the samples were large fragments of thin steel casing. The samples were collected from 333, and 342 fbls. These pieces of casing were a result of the vigorous brushing action that ripped off pieces of the deteriorated well casing.

Well UI#2 was pumped after brushing and bailing ended. Pumping began at 11:00 hours, and the pumping rate was measured with a five-gallon bucket and a stopwatch. The duration of pumping was for 30 minutes at rate of 80 gpm. Initially the pumped water flowed black due to the large amount of magnesium oxide precipitants suspended in the water. Water flowed clear after 20 minutes of pumping. The sediments needed to be removed to improve the clarity of the water column for video log documentation. While pumping, the depth to water in well UI#2 remained at about 52 fbls (2505.4 amsl). Pumping was terminated because the pump was becoming plugged due to the high concentration of suspended sediments. The depth to water was 52.2 fbls (2505.2 amsl) after pumping was terminated.

A video log was recorded by Golder Associates to a depth of 222 fbls. At that depth visibility was zero. In order to increase visibility for video logging, water was poured down well UI#2 from land surface on February 15, 2006 in an effort to flush the suspended sediments out of the bottom of the well into the formation. A three-inch hose was attached to a fire hydrant across the street at the corner of Paradise Creek St. and Stadium Dr. The hose was then placed into well UI#2 and allowed to flow for nearly an hour. However, using the hydrant caused a significant disturbance in the university water supply system so the activity ended. The alternative water source was located on the University of Idaho Facilities Compound approximately ¼ mile away from the UI#2 site. Three 300-gallon tank fulls of water were additionally poured down well UI#2. The exact amount of water that was drained into well UI#2 is unknown; however, the combination of the 900 gallons plus the flow from the three inch hose could equate to as much as 7,000 to 10,000 gallons.

A final video log was recorded on February 15, 2006 after water was poured down well UI#2. Visibility in the water column improved dramatically. An additional 112 feet of well was able to be video logged. During the final video documentation, the driller packed up their equipment and departed the UI#2 site. The video log documentation was completed to a final depth of 322 fbls where visibility was zero.

Approximately 35 cubic feet of sediments were bailed out of the bottom of well UI#2 during the cleaning process. The pile of sediments remained in the parking lot near the northwest corner of the UI#2 pump house for approximately two weeks. The drained sediments were shoveled into the back of a pick-up truck and hauled to the University of Idaho Waste Repository facility located in the UI Facilities maintenance yard.

Two DVD discs were made that compiled the preliminary and final video log notes on the condition of well UI#2 after cleaning. These two disks and the 2004 pre-cleaning DVD disc are filed by PBAC. Video log notes are presented in Appendix C. Figure 3.5 illustrates the condition of well UI#2 after cleaning.

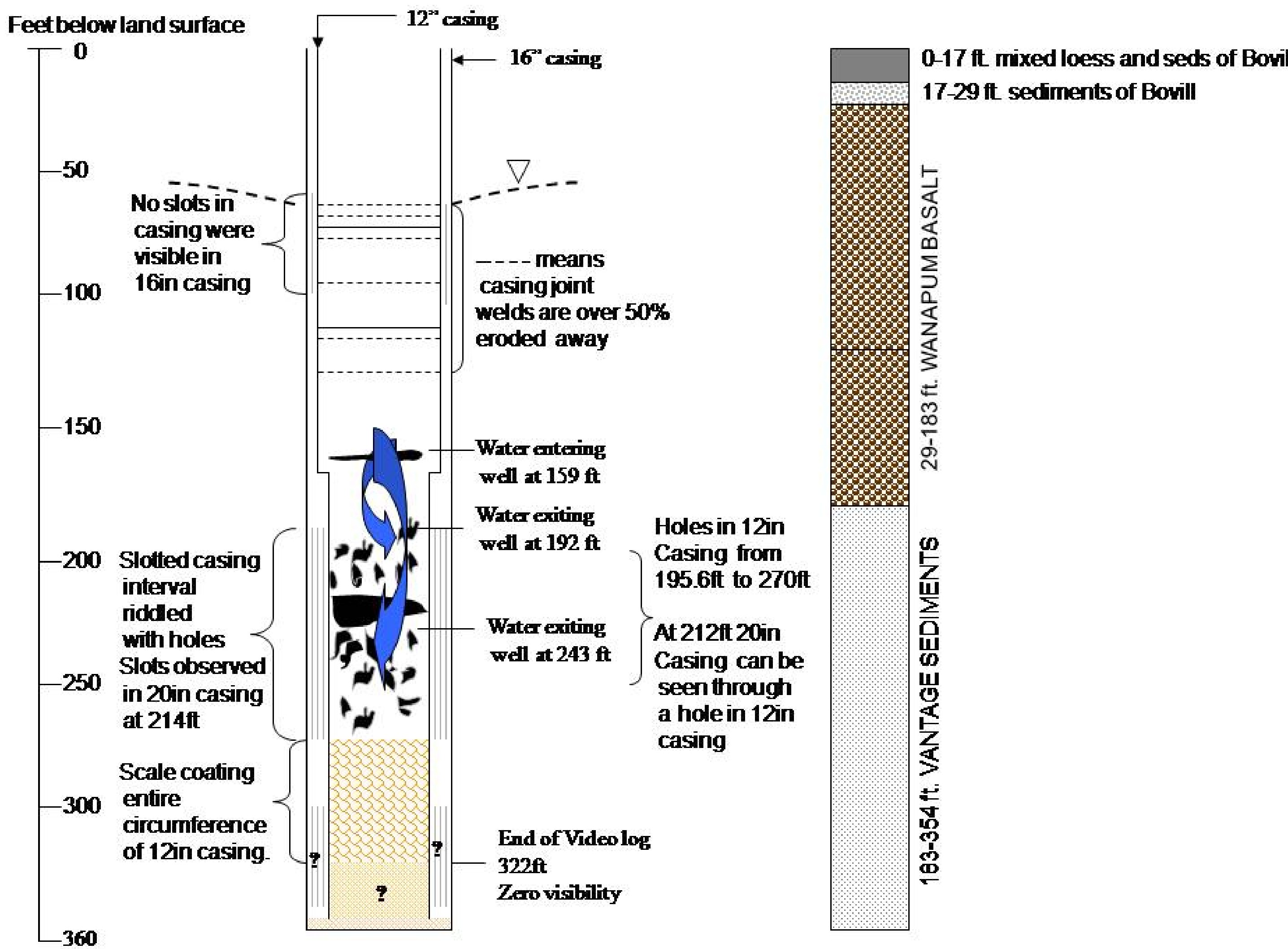

Figure 3. 5 Schematic of the well UI#2 after cleaning.

Brushing and bailing removed a significant portion of the sediments and scale contained in the well before cleaning. Based on the video logs, scale remained on the steel well casing from approximately 275 fbls to 322 fbls. The scale could not be removed due to problems with the brush becoming hung-up on holes in the casing.

A large number of individual casing joints were exposed by the well cleaning activities. Casing joints exist where individual sections of casing are welded together. In the interval from approximately 65 fbls to 125 fbls, six joints had over 50% of the welding material eroded away. No water flow was observed moving through these joints.

The first hole observed in the casing was at 159 fbls. The hole was approximately eight inches by one inch. It did not appear to be associated with a casing joint or slots. Water was observed flowing into the well through the hole. The flow was identified by the suspended particles that were entrained in the flow and the turbulent action paths they followed.

The holes in the casing were most concentrated where the 12” casing was slotted. The casing had become brittle, and the pieces of casing bailed from the well were probably from this section. The well video recorded an excellent view of the annulus between the 12” and 20” casing. A large amount of scale flakes could be seen settling out of the water in the annulus throughout the entire interval where the 12” casing was damaged due to brushing and bailing. Through the largest hole there was a view of coarse gravel size basalt grains grading down to fine sand size basalt grains that have accumulated between the 12” and 20” casing.

Water was first observed flowing out of the well at 192 fbls through a large hole in the 12” casing. The hole was approximately six inches by three inches. The flow was identified by suspended particles falling down vertically through the water column and abruptly changing direction as they flowed out of the borehole through the hole in the casing. Water was also observed flowing out of the borehole at 243 fbls through a hole that was approximately four inches by two inches.

3.2.3 Paradise Creek Monitoring Wells

The first step of the monitoring plan was to construct, and develop monitoring wells along Paradise Creek. These monitoring wells were installed to monitor changes that might occur in the sediments of Bovill due to cleaning and development of well UI#2. The locations for the wells along Paradise Creek were controlled by a variety of factors. Accessibility was the main concern because throughout the process of construction and development, bulky equipment such as a centrifugal pump, hoses, and buckets needed to be brought to the immediate location of the each well. A relatively flat, dry area was needed above the surface water of the stream for each monitoring well. Dry areas along the stream are most common during the end of the summer months. Three monitor well nests (N1, N2, and N3) were installed along Paradise Creek (Figure 3.6).

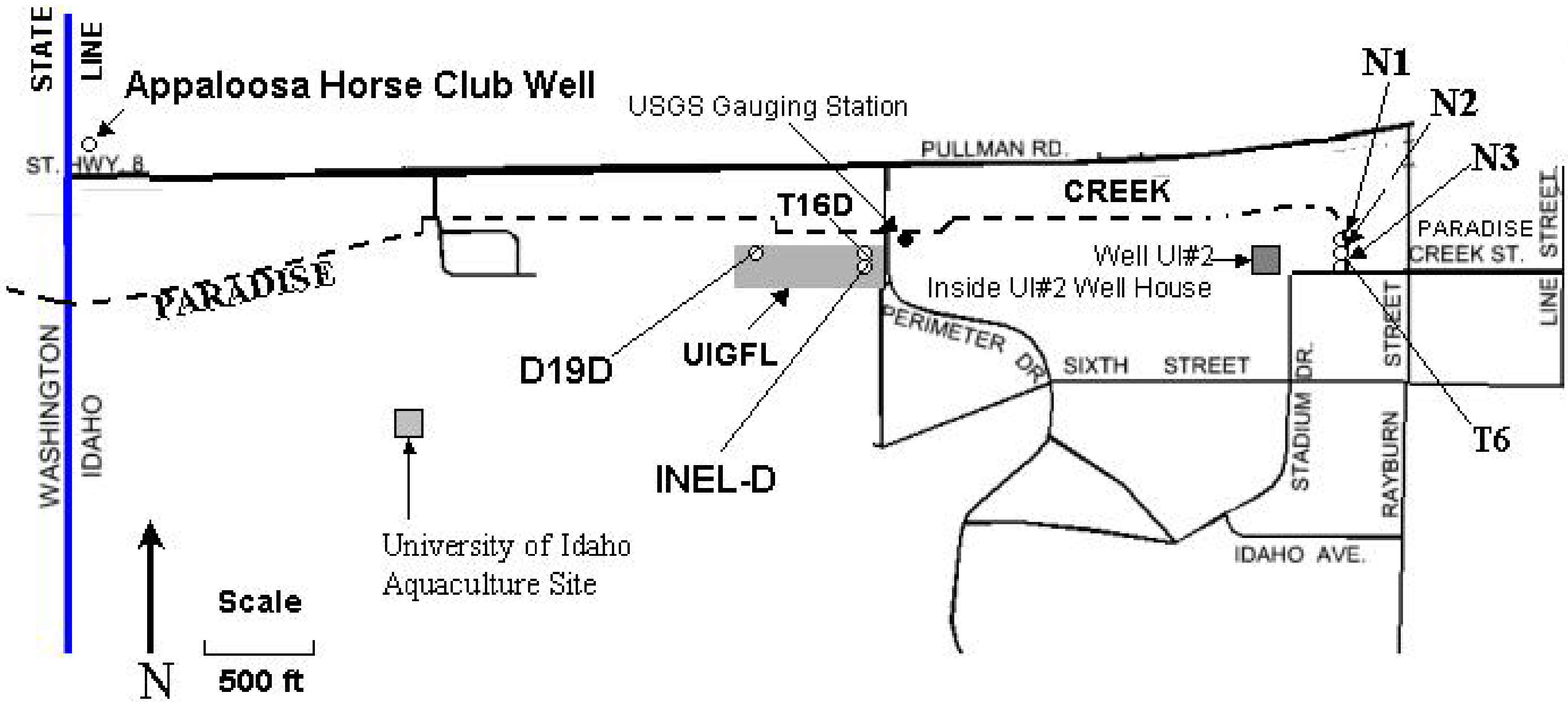

Figure 3. 6 Location map of the study area. The distance between the UI2 project site and UIGFL is approximately 2000 feet. No notable topographic features exist between the two sites.

Two monitoring wells were installed, one shallow and one deep, on each dry plateau at location N1 and N2. At location N3 only a shallow well was installed (Figure3.6). Each set of monitoring wells made up a monitoring well nest. Only the sediments augered form each ten foot deep monitoring well were logged because it was assumed that the stratigraphy did not change over the horizontal distance between two monitoring wells in a nest.

Well P1 is the shallow monitoring well in nest N1 (Figure 3.6). A five-inch diameter hole was augered by hand to a depth of four feet below land surface (fbls). From four to five fbls a four-inch diameter hole was augered. Five fbls was the depth that all shallow monitoring wells were completed. A high percentage of clay was encountered throughout the depth of P1 along with sand and coarse gravels. An approximately seven-ft length of two-inch diameter schedule 40 PVC pipe was glued and capped at one end. This end was perforated with a hacksaw over a one foot interval (Figure 3.7).

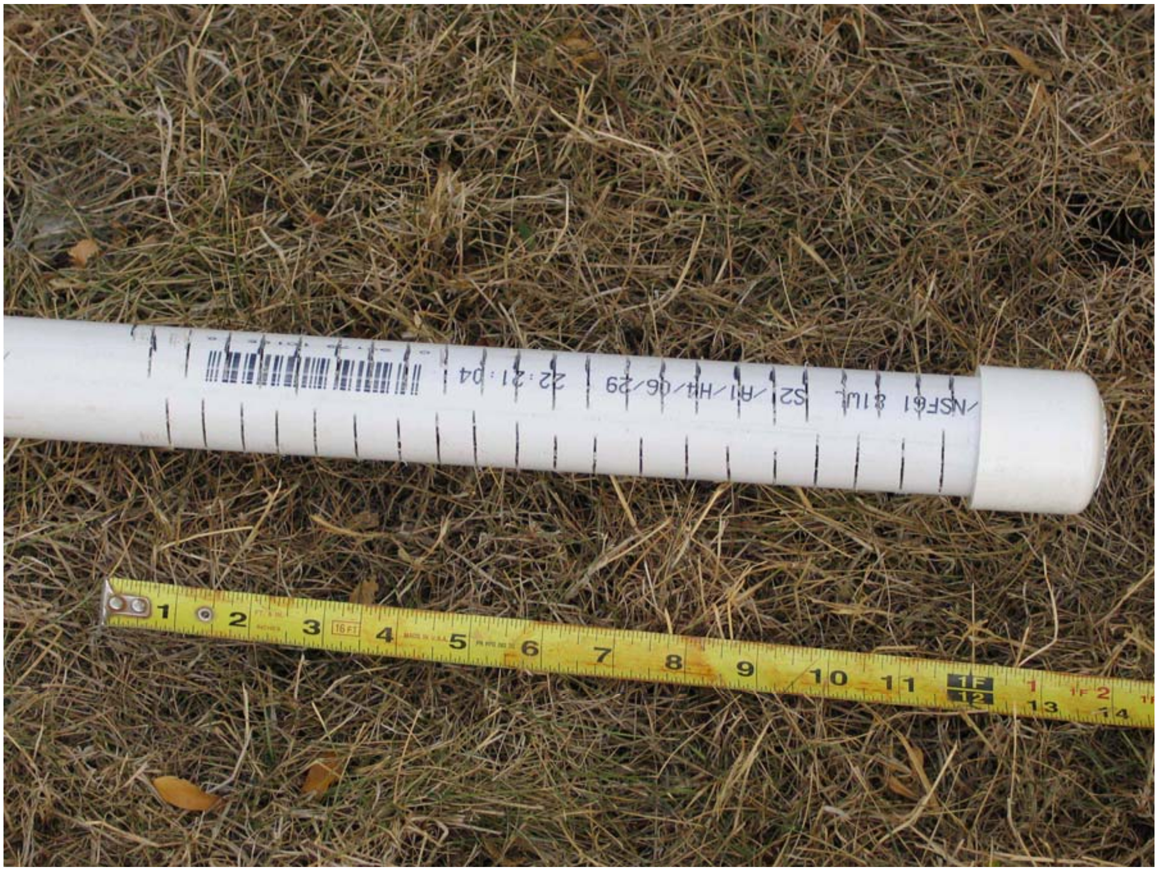

Figure 3. 7 Photo of the 12 inch perforation interval cut for each monitoring well.

The auger hole was backfilled with auger cuttings to the correct predetermined depth of five fbls before the PVC pipe was inserted. The PVC pipe was then placed in the hole and a sand pack was added to one inch above the top of the perforated pipe interval. A total of 20 inches of a mixture of pea gravel and auger cuttings were added above the sand pack. Finally, hydrated bentonite chips were used to fill the borehole to land surface. A threaded PVC pipe coupling was glued to the top of the 4.32 feet of PVC pipe that was above land surface. The adjoining threaded PVC cap was fixed with a system to secure this and each subsequent monitoring well to vegetation along the stream bank to protect the wells from high stream flows. A data logger was suspended below the water level in the PVC pipe on stainless steel cable. This system enabled the logger to be suspended at the same point after each data logger download.

Well P2 is the deeper monitoring well in N1 located approximately three feet away from P1. A five-inch diameter hole was augered to a depth of four feet below land surface. The five-inch auger was removed and replaced with a four-inch auger head to advance the hole to a depth of seven feet. Tightly packed clay and stones were encountered and a two-inch auger head was used to auger to a final depth of ten feet. Sediment samples for each augered foot were bagged and logged. A higher percentage of medium sands and fine sands exist from five feet to ten fbls. Because the last three feet of the borehole was approximately two inches in diameter, a 12-ft long section of 1.5-inch diameter schedule 40 PVC pipe was used. One end was glued and capped. This end was perforated over a one-ft interval in the same manner as P1. The hole was backfilled to the appropriate depth with auger cuttings and the PVC pipe was inserted. A 13-inch sand pack was placed around the perforated interval. A total of 20 inches of auger cuttings/pea gravel mixture was packed in the borehole evenly around the PVC pipe and above the sand pack. The remaining portion of the borehole was filled with hydrated bentonite chips to land surface. A threaded PVC cap was glued to the 2.75 feet of exposed pipe, and fitted with the same data logger suspension system used for P1. The same suspension system was used for all monitoring wells in N1, N2 and N3.

N2 is located approximately 50 feet upstream from N1 on the same stream bank (Figure 3.6). The first well (P3) was augered using a five-inch diameter auger head. Sediments were removed down to a depth of approximately ten fbls. Samples of the sediments were bagged for each one-ft interval. Medium sands made up the highest percentage of sediments encountered at this nest location. The hole was backfilled to a depth of 10 ft with auger cuttings. Then an approximately twelve-ft length of two-inch diameter PVC pipe was capped and perforated at one end and inserted into the borehole. A ten-inch length of sand pack was placed in the borehole, which extended one-inch above the top of the perforated pipe interval. A total of 20 inches of auger cuttings/pea gravel mixture was packed evenly around the PVC pipe and above the sand pack. The remaining portion of the borehole was filled with hydrated bentonite chips to land surface. A threaded cap was glued to the 2.96 feet of exposed PVC pipe above land surface.

Well P4 was constructed approximately two feet away from P3 in the N2. A five-inch diameter auger head was used to auger to a depth of about five fbls. The hole was back filled to a depth of five feet with auger cuttings. Then an approximately ten-ft length of two-inch diameter PVC pipe was capped and perforated at one end and inserted into the borehole. A ten-inch long sand pack was placed in the borehole, which extended one-inch above the perforated pipe interval. A total of 20 inches of auger cuttings/pea gravel mixture was packed evenly around the pipe and above the sand pack. The remaining portion of the borehole was filled in with hydrated bentonite chips to land surface. A threaded cap was glued to the 5.75 ft of exposed pipe above land surface.

N3 is located approximately 45 feet upstream from N2 on the same stream bank (Figure 3.6). The first borehole was augered with the five-inch augur head with sediment samples taken every one-ft. After augering to a depth of approximately five feet, a large cobble was encountered. Because this borehole was nearly five feet deep, it was completed as the shallow (P5) monitoring well in the N3. An approximately eleven-ft length of two-inch diameter PVC pipe was capped and perforated on one end and inserted into the borehole. A ten-inch long sand pack was placed in the borehole, which extended one-inch above the top of the perforated pipe interval. Twenty inches of an auger cuttings/pea-gravel mixture was packed evenly around the PVC pipe and above the sand pack. The remaining portion of the borehole was filled with hydrated bentonite chips to land surface. A threaded cap was glued to the 6.32 feet of exposed PVC pipe above land surface.

A second borehole was augered; however, another large cobble was encountered at approximately the same depth. A sediment layer with a high percentage of cobble size grains in a sand and clay matrix exists at this location. Completion of a deeper monitoring well in N3 was not possible because of this cobble/sand/clay layer. Therefore, the second borehole was backfilled with the augered material in the same order the sediments were removed and abandoned.

Figure 3.8 presents the geologic logs of the materials encountered for N1, N2, and N3 based on sediment samples collected every one-ft.

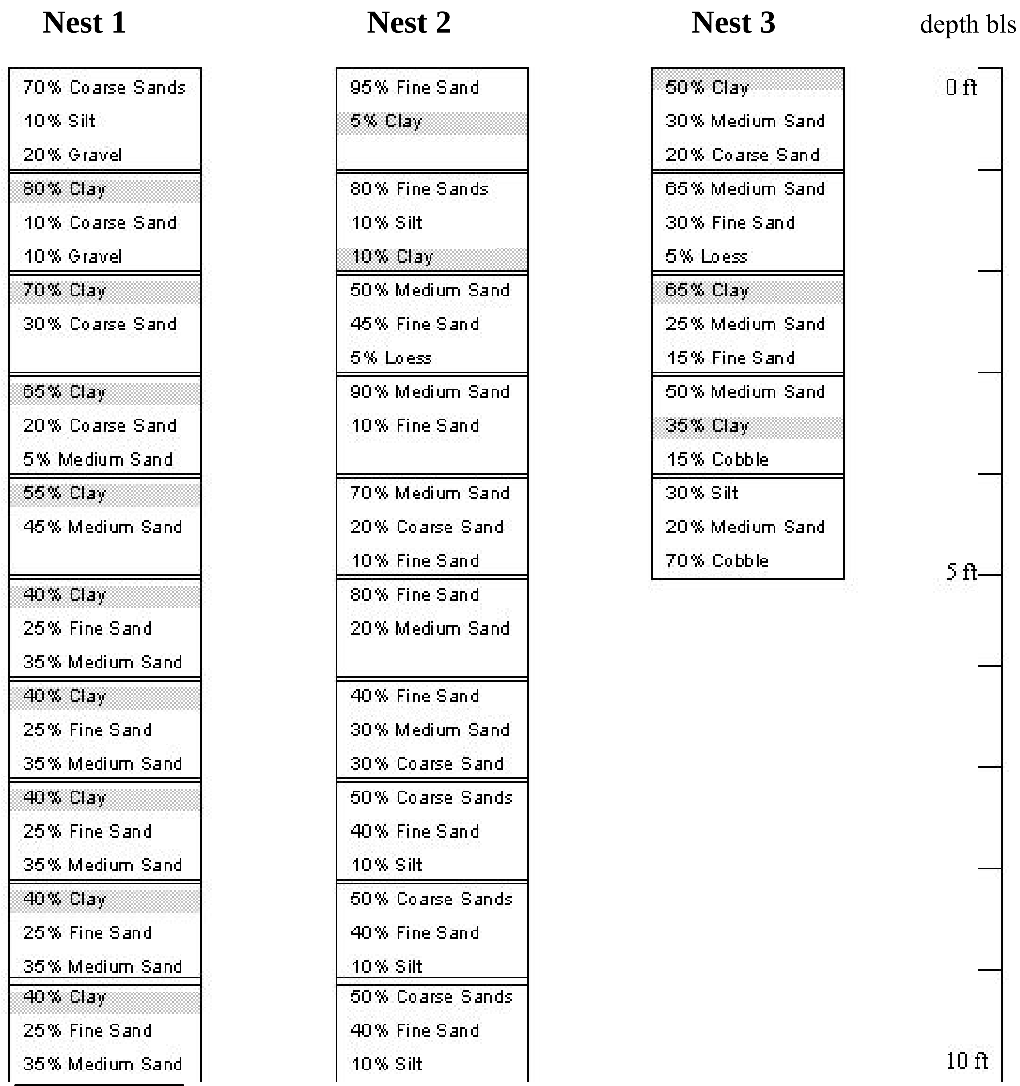

Figure 3. 8 Geologic well logs for the Paradise Creek Monitoring wells. The percentages of grain sizes shown represent the materials encountered over one-ft intervals in each borehole. Shaded zones represent potential clay aquitards.

All monitoring wells were developed by pumping water out of the borehole using a portable, gasoline powered, centrifugal pump. Each well was pumped multiple times until the water flowed clear. At this point the monitoring well was considered developed.

The final step taken before the monitoring wells were ready for monitoring was to survey the elevation of the top of the PVC casing. The well UI#2 wellhead was used as a known reference elevation to survey the Paradise Creek monitoring wells using a surveying equipment package from LevelRite™. Three transects were delineated to survey the wells in N1, N2, and N3. A surveying staff equipped with a laser-sensor and a tripod-mounted laser were used to project the elevation of UI2 wellhead to the stream bank above each nest. The tripod was then repositioned in a direct line of sight to each monitoring well so the elevation of the top of the monitoring well pipe could be measured to an accuracy of 0.01 feet (3mm). The elevation for each monitoring well is shown in Figure 3.9.

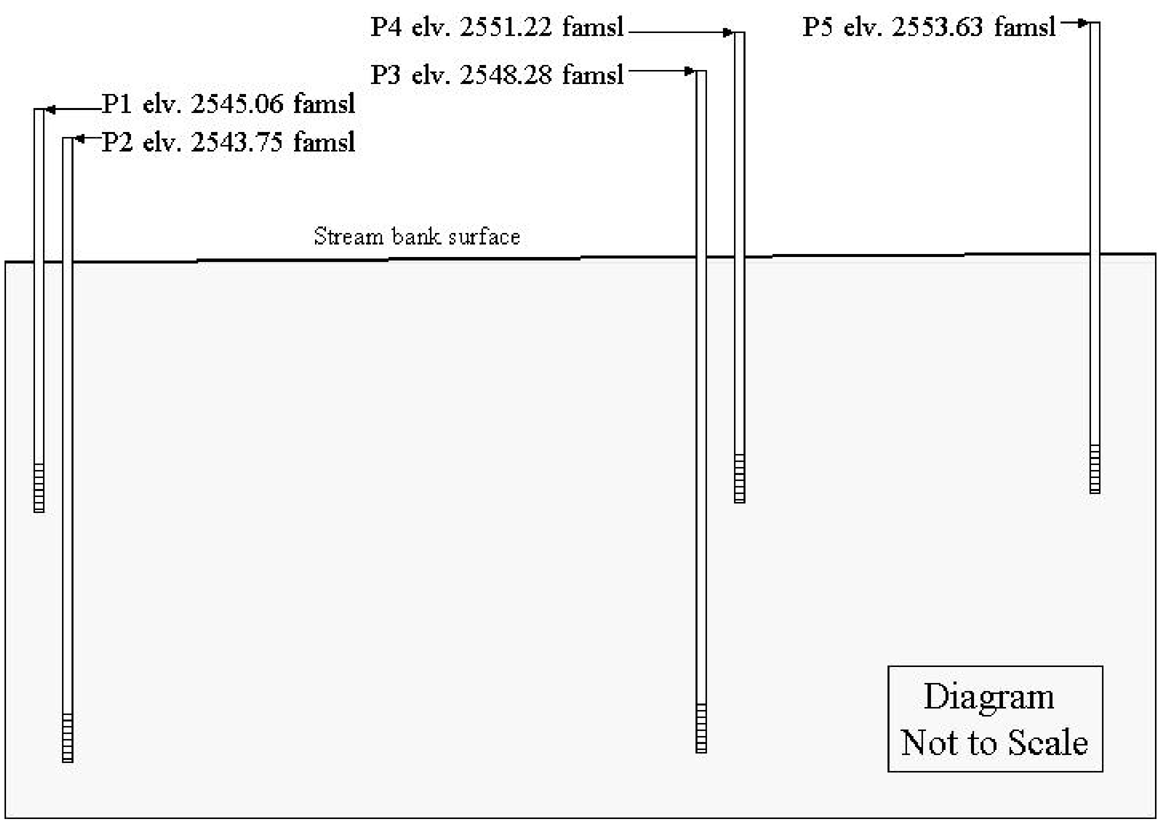

Figure 3. 9 Elevation of the wellhead for each Paradise Creek monitoring well.

During cleaning of well UI#2, water levels and temperatures were monitored in Paradise Creek, and in the Paradise Creek monitoring wells to detect changes due to cleaning UI#2. Monitoring wells P1 through P5, and Paradise Creek were monitored during Cleaning Periods 1, 2 and 3. If cleaning activities did cause changes in water levels in the sediments of Bovill, then based on the conceptual model, the cone of depression would have grown through the Wanapum basalt and affected the sediments of Bovill. The water levels in the sediments of Bovill were expected to decline due to cleaning activities in well UI#2.

The correlation analysis tool in Microsoft Excel™ was used for analysis of water level and temperature data. Correlations were run after the slope analyses for comparison. Slope analysis is a visual technique, which may bias the analysis because the change in water levels may only be able to be recognized statistically. Correlation analyzes the change between consecutive data points in each data set. From the data point at time t=0 to t=1 in each data set, the change is compared between the data sets. This incremental comparison repeats for t=(n-1) to t=n. Where n is the number of data points in each data set being correlated. A correlation value is calculated based on how similar the change is between the two data sets. Correlation is computed into what is known as a correlation coefficient, which ranges between -1 and +1. Perfect positive correlation (a correlation coefficient of +1) implies that as one data value moves, either up or down, the associated data value will move in lockstep, in the same direction. Alternatively, perfect negative correlation means that if one data value moves in either direction the associated data value that is perfectly negatively correlated will move by an equal amount in the opposite direction. If the correlation is 0, the movements of the data values is said to have no correlation and the data values association is completely random.

Water levels for Paradise Creek monitoring wells were correlated with Paradise Creek stage height data, and correlation coefficients were calculated. The lag times between stream stage fluctuations and the associated monitored water level responses were evaluated to correlate the two systems. Because Paradise Creek stage controls the water levels in the monitoring wells, fluctuations in ground water levels lag behind the creek fluctuations.

3.2.4 Existing Monitoring Wells

Selected wells at the University of Idaho Groundwater Field Laboratory completed in the Wanapum Aquifer System were monitored as part of this investigation. Because the location of the UIGFL is approximately 2000 ft to the west of well UI#2, it can be assumed that the geology is similar at both sites (Figure 3.10).

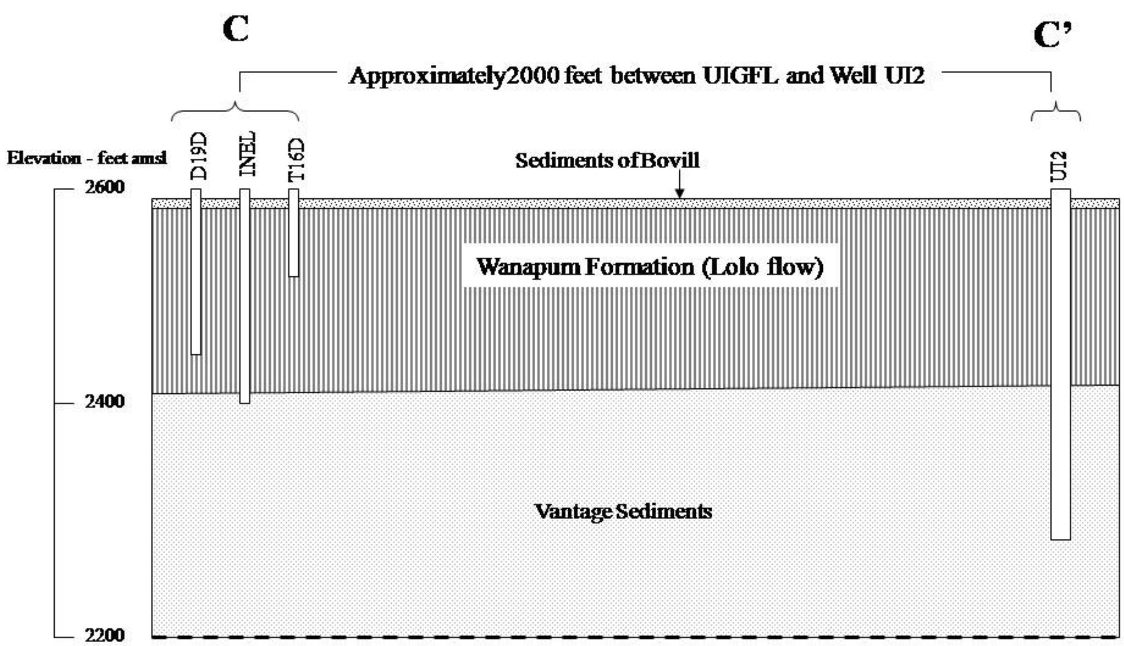

Figure 3. 10 Geologic cross section from the UIGFL to well UI2. The figure includes the monitoring wells from the UIGFL used in this project. They include INEL-D, D19D, and T16D. The location of cross-section C-C'is shown on Figure 1.1.

Three wells, T16D, D19D, and INEL-D, were selected for monitoring at the UIGFL (Figure 3.6).

T16D is a monitoring well completed into the Lolo flow of the Priest Rapids Member of the Wanapum Formation. The construction details and geologic well log for T16D are shown in Figure 3.11.

WELL LOG FOR T16D WELL

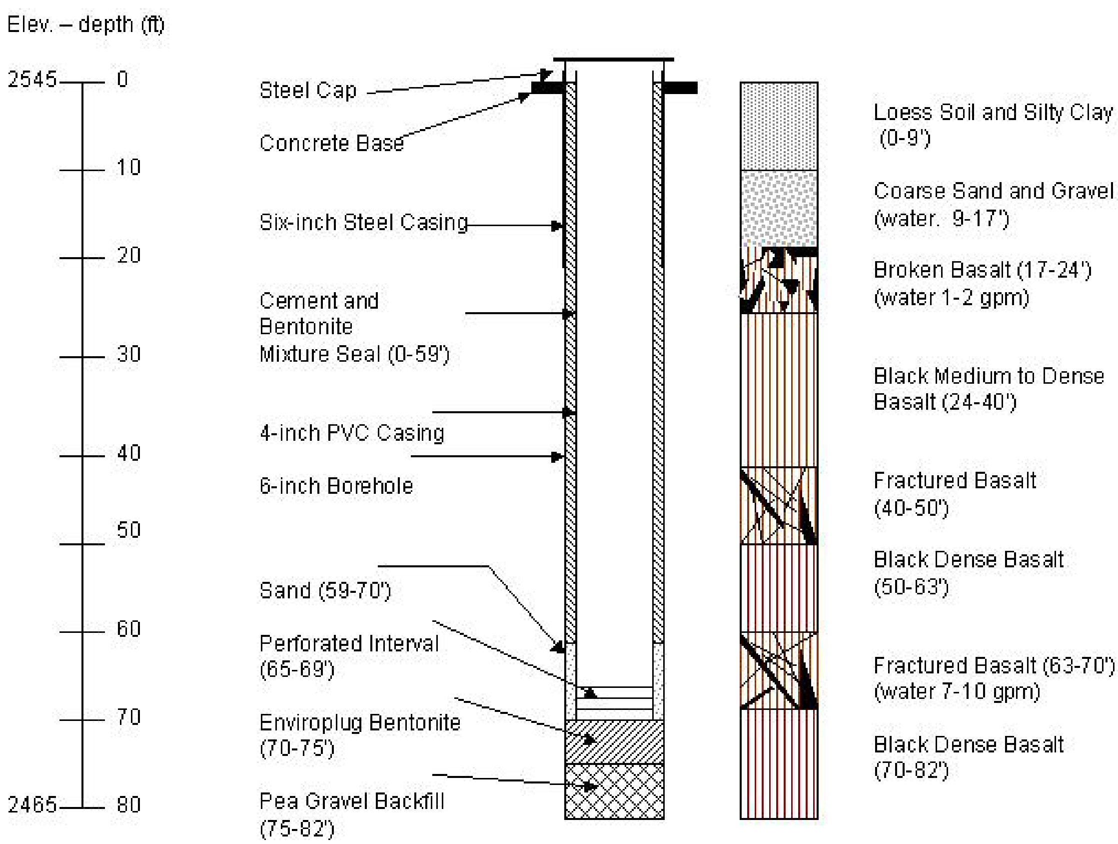

Figure 3. 11 Monitoring well T16D well log and construction details. The monitoring well T16D is located at the UIGFL site (Figure 3.6). (Modified from Li, 1991)

T16D was used to monitor water levels in the in the Lolo basalt flow during the investigation. The second monitoring well was INEL-D (Figure 3.12). This well is completed three feet below the Lolo flow into the Latah Formation sediments (Vantage) (Figure 3.10).

WELL LOG FOR INEL-D WELL

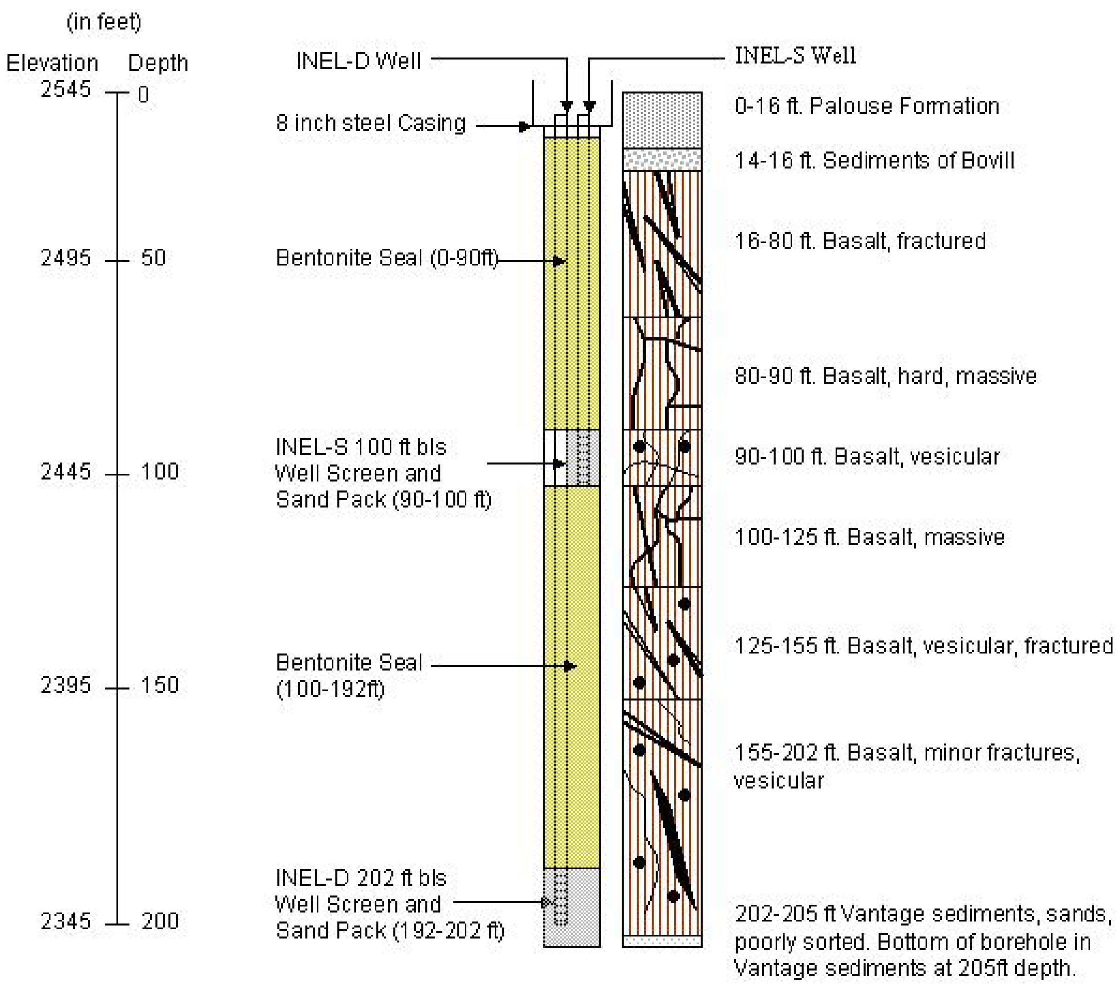

Figure 3. 12 Monitoring Well INEL-(S and D) well log and construction details. Well INEL-D is located at the UIGFL site (Figure 3.6). (Modified from Kopp, 1994)

INEL is a multiple level monitoring well. The multiple levels consist of a shallow (S) and deep (D) well. INEL-S is designed to monitor water levels in the Lolo flow of the Wanapum Formation. INEL-D is designed to monitor water levels in the Vantage sediments. INEL-S was not monitored as part of this project.

The three selected UIGFL wells (T16D, D19D, and INEL-D) were incorporated into the ground water monitoring network to monitor the Wanapum basalt and Vantage sediments, respectively, which were expected to be potentially impacted by well UI#2 cleaning and development.

3.2.5 Paradise Creek Data Collection

Several additional data sets were compiled during this investigation. The first data set consists of data logger recorded stream stage height measurements for Paradise Creek at location T6 (Figure 3.6). These data were used to evaluate hydraulic connections between Paradise Creek and the ground water systems. The second data set was a stream stage record for Paradise Creek from the United States Geological Survey gauging station for the year 2006.

The data logger labeled T6 was submerged in the stream channel for the duration of the project (Figure 3.6). T6 monitored stage height and water temperatures for Paradise Creek for comparison with water data collected for the Paradise Creek monitoring wells. T6 remained stationary in the stream channel once covered by accumulated streambed sediments. Sediments did not become plugged in the data logger sensor port of T6, because the grain sizes were either larger or smaller than the 0.01-ft diameter opening.

Paradise Creek stage height data also were obtained from the (USGS. gage #13346800) gauging station located on Paradise Creek (Figure 3.6). Data for September 2005 to March 2007 were downloaded from the USGS Water Resources of Idaho web site (http://waterdata.usgs.gov/id/nwis/sw).

3.2.6 PBAC Wanapum Database

Water level data and temperature data for selected wells in the PBAC, Wanapum database were used in this investigation. Water level data collected over the duration of this project were compiled. Only wells that might be influenced by cleaning and development of well UI#2 were considered. Water level data collected for wells that are completed in the Lolo basalt and Latah Formation sediments are considered because well UI#2 is assumed to have open intervals in these units. These data were used to evaluate the potential effects caused by the cleaning of well UI#2.

3.3 Tracer Tests

Four months after cleaning well UI#2, several tracer tests were conducted to help quantify the volume of water flowing downward in the borehole. The tracer tests were designed based on borehole conditions derived from the post-cleaning video log. Note, the methods and results of all tracer tests are presented in Appendix A.

Cleaning of UI2 perturbed the "steady-state" ground water conditions near the well. Once the system was changed, it evolved towards a new steady-state condition. However, because no tracer tests were conducted before well UI#2 was cleaned, it is not known if the cleaning increased or decreased the flow in the well.

Eight tracer tests were conducted over a four-month period. Two tests were conducted by pouring warm water down the well from land surface; this type of test was designated a land surface (LS) tracer test. Six tests were conducted by injecting warm water at a point within the borehole flow environment; this type of test was designated a point-tracer (PT) test. For both test types, a series of data loggers were suspended in the water column on a 1/8 inch nylon rope to record temperature changes as the warm water moved within the borehole. For each tracer test, the data loggers were set to record background temperatures for at least 60 seconds before the test started. A majority of the tests had the data loggers set on a one-second sampling intervals except where noted for individual tests. Each data logger was allowed to record continuously for a minimum of three hours or until the memory was filled.

CHAPTER 4 DATA ANALYSIS AND DISCUSSION

4.1 Introduction

Analysis of temperature and water level data collected from Paradise Creek monitoring wells, local monitoring wells, and University of Idaho Well #2 was used to identify whether changes in the local ground water system occurred as a result of cleaning activities in well UI#2. These activities cleared accumulated sediments from the bottom of the well and removed scale deposited from the inner casing by brushing and bailing. The timing of changes observed in the monitoring well data are related to the cleaning activities in well UI#2 from February 10, 2006 until February 15, 2006. The total cleaning process was completed over 29-hours spread over the daylight working hours of three days. However, an increase in flow out of the bottom of well UI#2 may have occurred sometime between 07:00 hours and 11:00 hours on 02/14/2006. During this time, pieces of casing were bailed out of well UI#2 and it is assumed that an increase in flow rate out of the bottom of UI#2 may have begun at that time.

Perturbation of the system originally was expected to have caused a cone of depression to develop in the Lolo basalt, and a cone of impression to form in the Vantage sediments. Water levels in monitoring wells completed in the sediments of Bovill were expected to decline in response to the increases in the rate of water draining down well UI#2 (Figure 4.1).

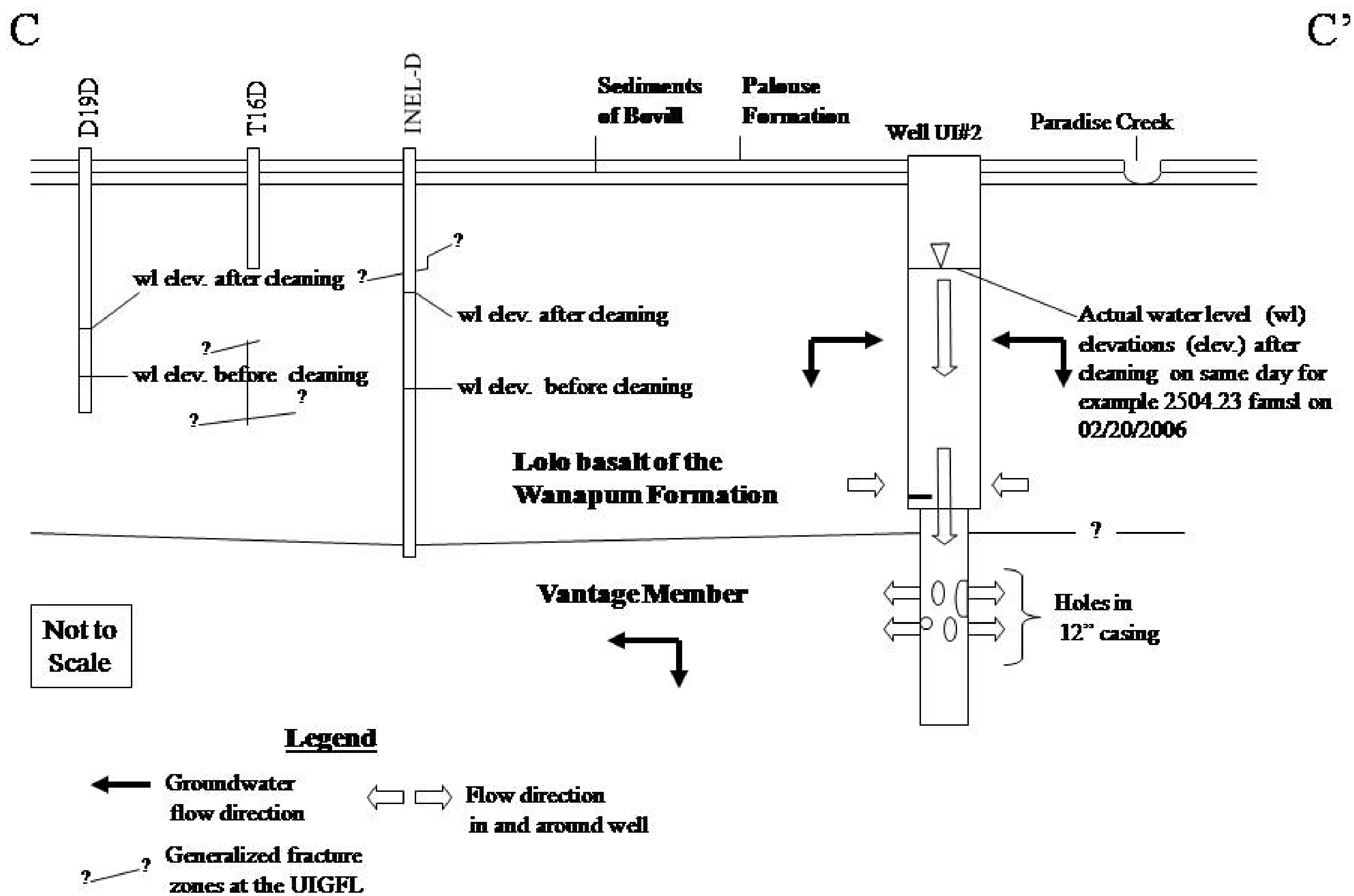

Figure 4. 1 Original conceptual groundwater flow model after cleaning. Cleaning well UI#2 was expected to affect the groundwater flow environments in each geologic unit.

Conceptually, well UI#2 can be viewed as a cylindrically shaped, vertical conduit that drains groundwater from the sediments of Bovill and the Lolo basalt vertically down into the Vantage sediments. Draining of water into the Vantage sediments from the well bore forms a cone of impression (i.e., ground water mounding) that extends radially outward from well UI#2. A cone of depression forms in the Lolo basalt as ground water flows into well UI#2. This cone of depression captures ground water in the Lolo basalt, from the hydraulically connected sediments of Bovill, and from Paradise Creek. The cone of depression in the Lolo basalt and sediments of Bovill grows until a steady state equilibrium is reached.

4.2 Analysis of Design and Implementation of Monitoring Network

The following section describes the methods of analysis used to interpret data sets collected at the UIGFL, in UI#2, and in the vicinity.

4.2.1 Analysis of Field Collected Data

It is important to note that it was necessary to apply a discrepancy correction to the data sets for each monitoring well. For uncertain reasons, a discrepancy between the hand measured water levels and the water levels recorded by the data loggers occurred each time the data loggers were downloaded, reset and replaced in the monitoring wells. The cause of the discrepancy is not known; however, the discrepancies manifest themselves as “jumps or offsets” in plots of water levels versus time. These jumps or offsets range in magnitude from tenths of feet to greater than one foot at the exact times the data loggers were downloaded. These offsets are considered to be errors and not real water level changes; therefore in order for the data to be analyzed, these offsets needed to be corrected. Discrepancies between water levels measured before and after data logger downloading were filtered from each data set by adjusting the post-download portion of the data set. Water level data were shifted up or down as needed to make the last water level measurement recorded prior to logger download correspond with the first measurement recorded after the data logger was reset and replaced in the well.

These shifts corrected the offsets and made seamless transitions from one data set to the next. The discrepancies were corrected first, and then the entire data set for each well was evaluated using BETCO to correct for barometric pressure effects. The source of the discrepancies has not yet been defined but is probably due to human error during downloading and resetting of dataloggers.

The USGS stage height data were compared with the water level data collected by the T6 data logger. Comparison of the data sets confirmed that the T6 data logger remained properly positioned in the thalweg of the stream over the duration of the project.

Tracer tests conducted in well UI#2 after cleaning were preliminary work to help design an optimal visual dye tracer test. The design would include injection of a dye tracer at a point in the borehole while a submersible borehole camera below the injection point recorded a visual arrival time of the dye tracer. Note: the visual dye tracer test was beyond the scope of this investigation. Details derive from the preliminary tracer tests may provide the depth of understanding needed to know where to inject the dye and place the camera during the implementation of the dye tracer tests.

4.2.2 Analysis of Data Collected in Well UI#2

Ground water samples were collected from well UI#2 for chemical analysis prior to the beginning of this investigation. The Idaho Department of Water Resources (IDWR) required a chemistry report that listed the levels of constituents in the ground water flowing into well UI#2 from the Wanapum Formation. The results of the groundwater analyses from Anatek Labs in Moscow, Idaho were sent to IDWR. IDWR granted permission for this investigation to proceed, based on the acceptable groundwater quality in well UI#2.

Water level measurements were taken in well UI#2 before and after cleaning, and two water level measurements were taken during cleaning activities. The water level elevation in well UI#2 was 2497.48 famsl after bailing activities ended on 02/10/2006; this water level represented a 5.17 foot decline from the 02/01/2006 pre-cleaning water level measurement. The water level elevation after cleaning activities ended on 02/14/2006 was 2505.2 famsl. The last water level measurement was 2502 famsl taken on 03/03/2006. These oscillating water levels about the baseline water level taken before cleaning activities started do not support a water level increase needed to significantly increase the borehole flow downward in well UI#2. Well UI#2 water levels returned to baseline on 03/03/2006 which suggested that water flow in the borehole did not change significantly during cleaning and returned to baseline approximately 16 days after cleaning activities ended. This evidence also demonstrates that no significant permanent change in the borehole flow environment occurred as a result of cleaning activities in well UI#2.

4.2.3 Analysis of Paradise Creek and Sediments of Bovill Data

Water levels in Paradise Creek monitoring wells fluctuated in a similar manner to the stage height fluctuations in Paradise Creek. The magnitude of water level fluctuations in the monitoring wells was attenuated due to the high clay content in the sediments of Bovill in the area of each nest (Figure 3.8). Figure 4.2 is an arithmetic plot of water levels versus time for all Paradise Creek monitoring wells during Cleaning Period 1 from February 2, 2006 to February 10, 2006.

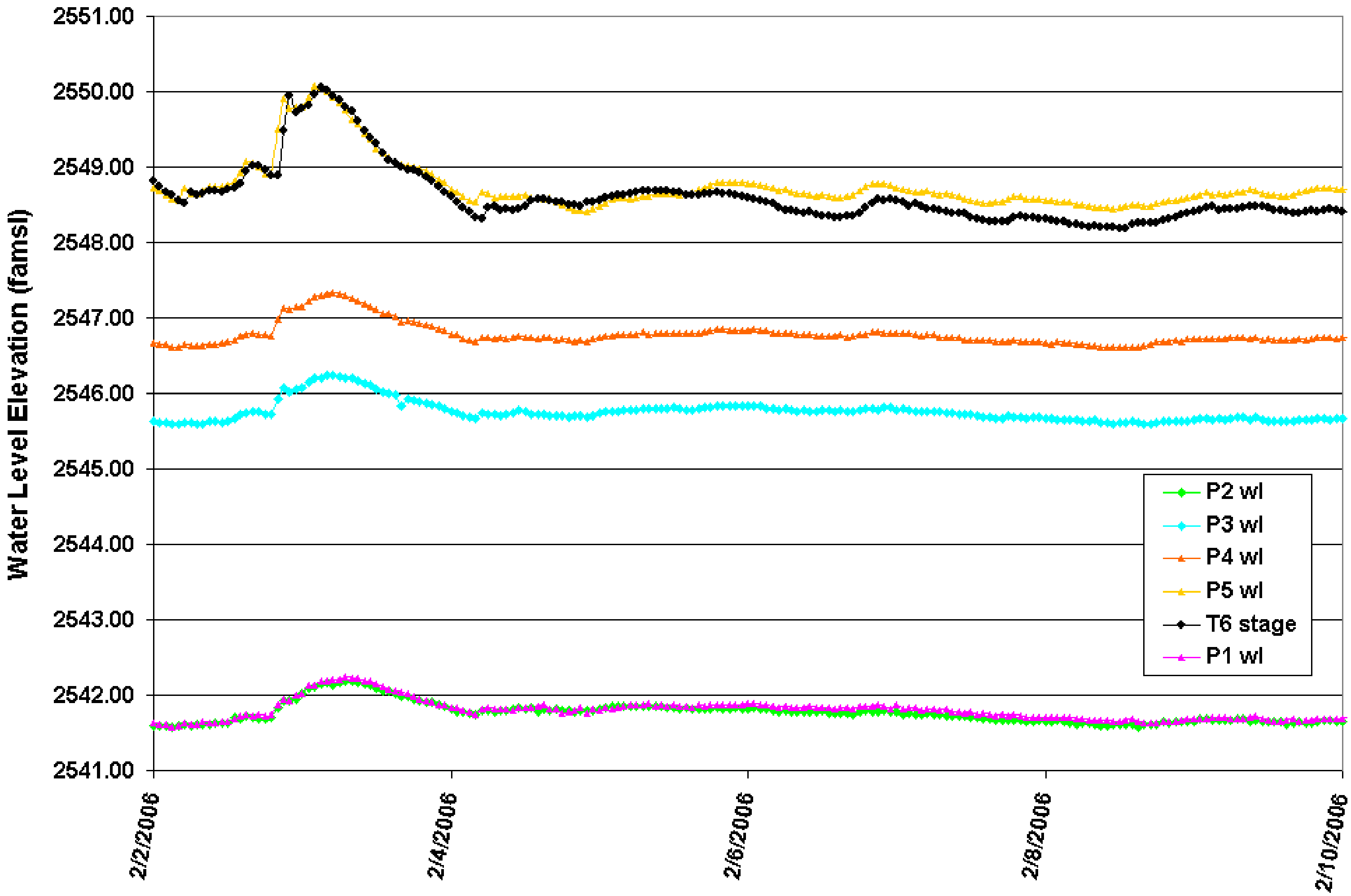

Figure 4. 2 Arithmetic plot of hourly water level measurements during cleaning Period 1for Paradise Creek monitoring wells P1 through P5, and Paradise Creek at measurement locationsT6.

The spike in stream stage height on February 3 shown in the plot for T6 was in response to a precipitation event. The effects of the high stream stage pulse was observed in all monitoring wells demonstrating hydraulic connection between Paradise Creek and the sediments of Bovill in this area. Water level elevations indicate that Paradise Creek generally was losing water at this location to the underlying groundwater system. However, the movement of water from Paradise Creek into the groundwater was not well defined in the water temperature data collected during Cleaning Period 1 (Figure 4.3).

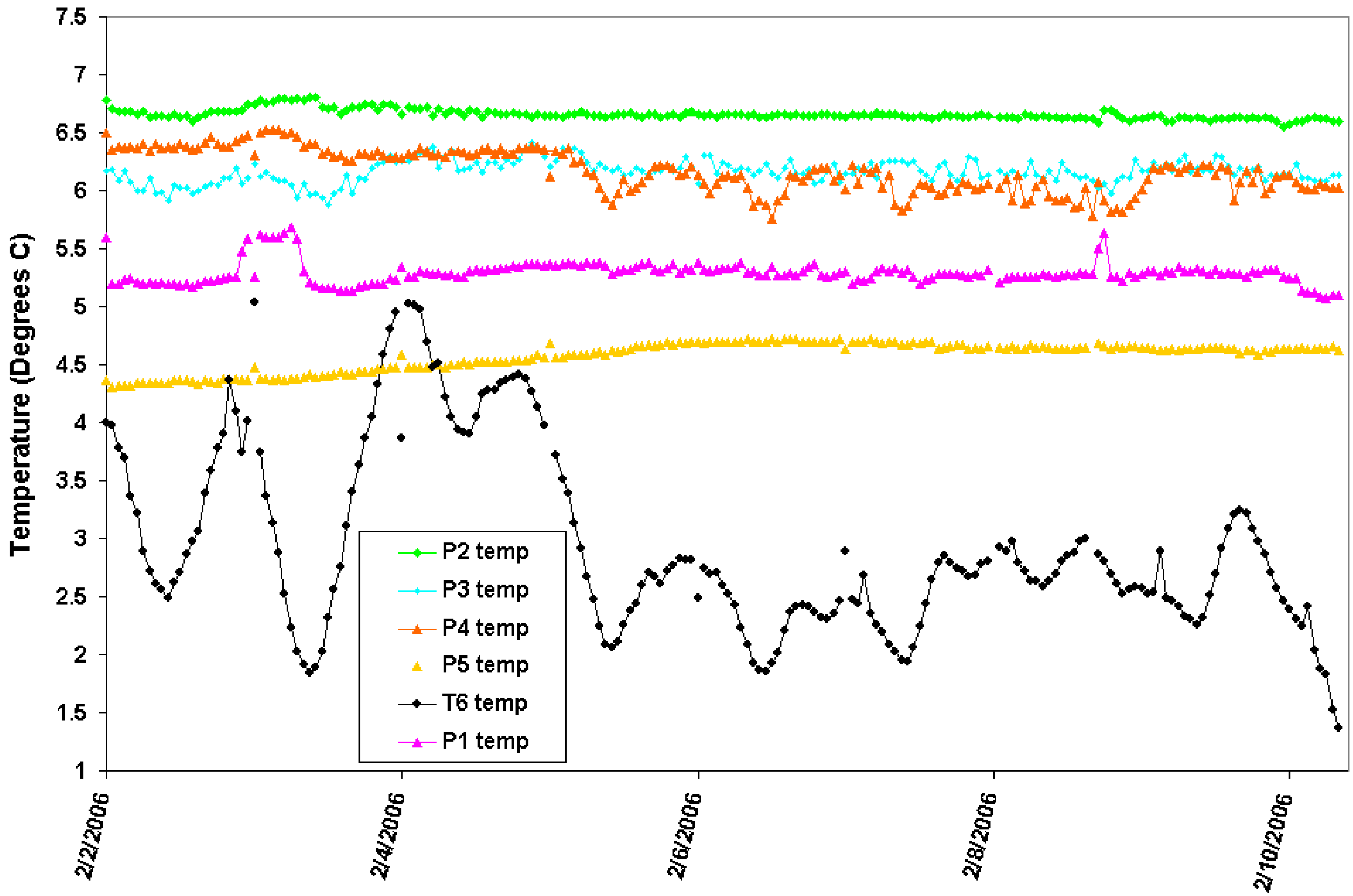

Figure 4. 3 Arithmetic plot of hourly water temperatures during Cleaning Period 1for Paradise Creek monitoring wells P1 through P5, and Paradise Creek at measurement location T6.

The indications that water level fluctuations in P5 corresponded with fluctuations in Paradise Creek stage, and the water level elevations for P5 were higher that Paradise Creek stage most likely reflect surveying error. Comparison of Figure 4.2 and 4.3 shows that monitoring well water temperatures fluctuated radically compared to water levels over the measurement period. However, changes in temperature lag well behind the changes in water levels (i.e., pressure) because temperature changes require the actual movement of water molecules where as the migration of a pressure pulse is very rapid.

Water level elevations for all Paradise Creek monitoring wells and T6 were plotted during cleaning periods 1, 2, and 3 from 02/02/2006 to 03/03/2006 (Figure 4.4).

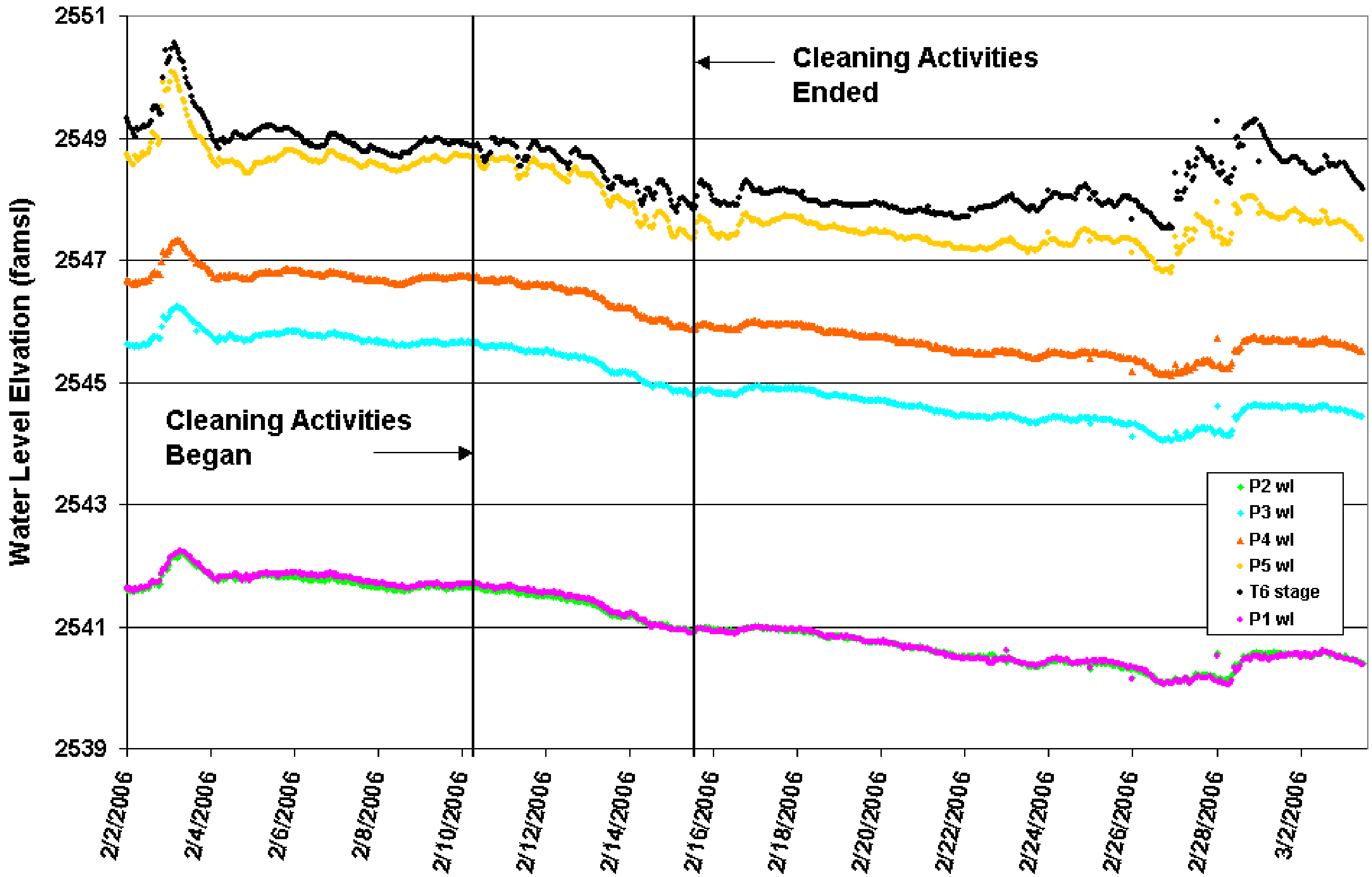

Figure 4. 4 Arithmetic plot of hourly water level measurements during Cleaning Periods 1 through 3 for Paradise Creek monitoring wells P1 through P5, and Paradise Creek at measurement location T6.

When cleaning began, no apparent response was observed in the monitoring wells. However, at approximately 08:00 hours on 02/13/2006 a change or "dip" occurred in the downward water level trends in all monitoring well water levels and Paradise Creek stage height. The fact that the water levels "dipped" and then recovered back to pre-existing trends suggests that cleaning activities in well UI#2 may have been the cause. However, a similar dip occurred on 02/26/2006 at approximately 08:00 hours, well after cleaning activities ended, suggesting that the cause of both dips was unrelated to well cleaning. These two changes in the system were due to something other than cleaning activities in well UI#2.

Water temperatures for all Paradise Creek monitoring wells and T6 were plotted during cleaning periods 1, 2, and 3 from 02/02/2006 to 03/03/2006 (Figure 4.5).

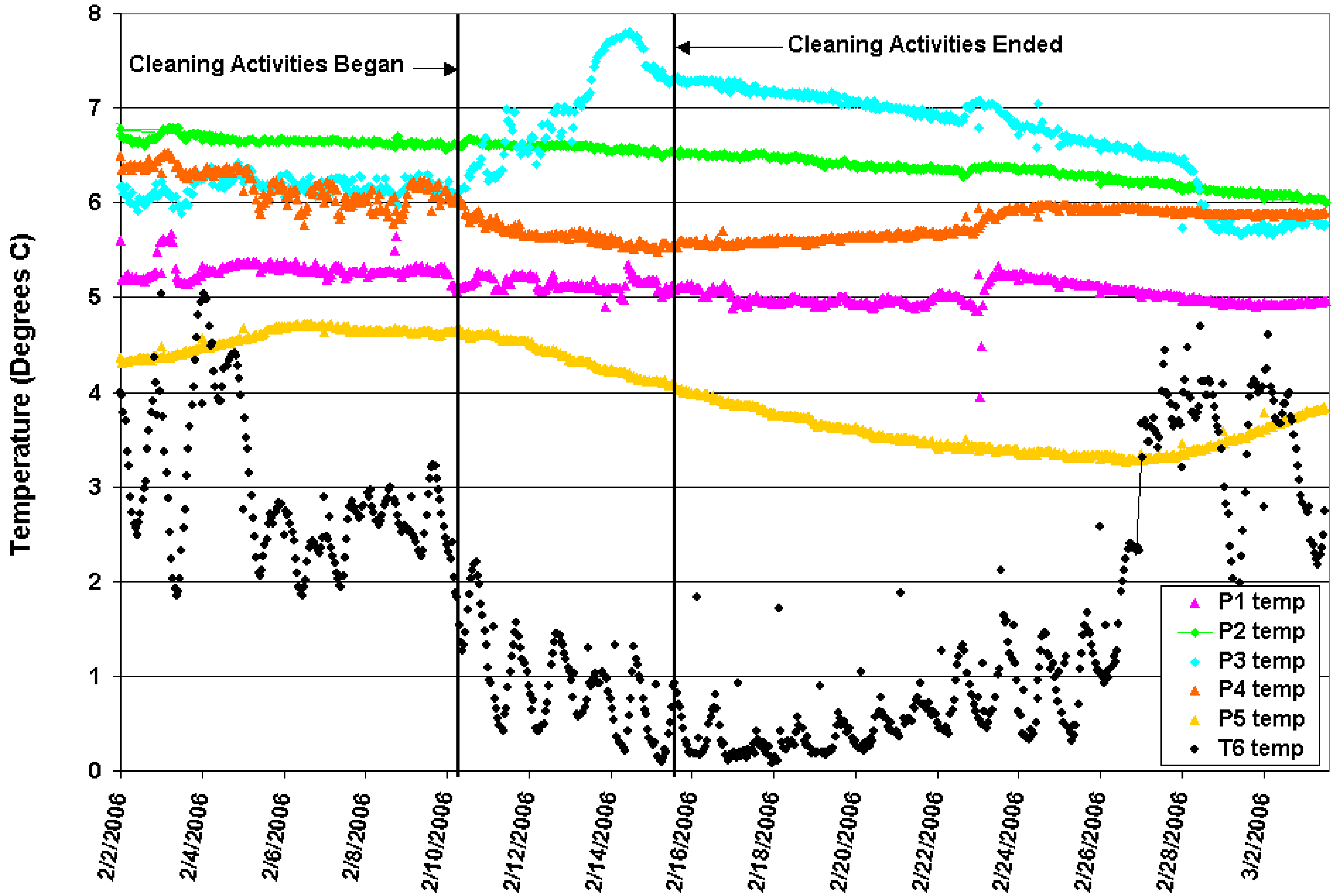

Figure 4. 5 Arithmetic plot of hourly temperature measurements during Cleaning Periods 1 through 3 for Paradise Creek monitoring wells P1 through P5, and Paradise Creek at measurement point T6.

Ground water temperatures during cleaning periods 1, 2 and 3 show similar trends in response to water temperature fluctuations in Paradise Creek. Ground water temperatures appeared to change when cleaning began and 13 days after cleaning ended. Decreasing temperatures were seen in wells P1, P2, and P4 while rising temperatures were seen in well P3. These two responses are not associated with Paradise Creek fluctuations. The first response coincided with the start of cleaning activities but can be discounted as a result of cleaning activities because the aquifer system responded in a similar manner only with a smaller magnitude on 2/23/2006.

Water levels in Paradise Creek monitoring wells were correlated with Paradise Creek stage height. The comparison showed statistically that the water levels in the monitoring wells and in Paradise Creek fluctuated similarly. Table 4.1 compares correlation coefficients derived in Excel for each cleaning period 1, 2, and 3.

Cleaning Period 1	**P1**	**P2**	**P3**	**P4**	**P5**
T6	0.57	0.67	0.63	0.87	0.91
Cleaning Period 2	**P1**	**P2**	**P3**	**P4**	**P5**
T6	0.92	0.92	0.94	0.94	0.98
Cleaning Period 3	**P1**	**P2**	**P3**	**P4**	**P5**
T6	0.68	0.62	0.79	0.81	0.84

Table 4. 1 Correlation coefficients of the correlation between the water levels for T6 and P1 through P5. Paradise Creek stage height fluctuations (T6) were correlated with measured water levels in Paradise Creek monitoring wells P1 through P5 for each cleaning period.

Correlation coefficients were also evaluated with the observed lag time between water levels in the monitoring wells and Paradise Creek stage height. The lag times were based on the length of time between when Paradise Creek began to spike and when monitoring well water levels began to rise later in time. Wells in nests N2 and N3 responded within the same hour while nest N1 wells showed a six-hour lag. Correlation of one-hour lag through a six-hour lag did not change the magnitude of the correlation coefficients significantly (change of 0.001). Because all correlation coefficients are closer to positive one than zero means that as monitoring well water levels fluctuated, either up or down, the associated stream stage height fluctuated in lockstep, in the same direction. Clearly, water levels in the monitoring wells nearly mirrored the stream stage measurements at T6 and the correlation coefficients support that observation.

4.2.4 Water Levels in Local Monitoring Wells

During cleaning of UI#2, water levels and temperatures were monitored in nearby wells to detect changes due to cleaning activities. Well INEL-D, D19D, and AHC were monitored for the duration of cleaning. Water level fluctuations in these wells appeared to correspond with cleaning activities conducted in well UI#2.

Water level data for the three monitoring wells were analyzed using the aquifer test analysis program AQTESOLV™. The solution used for all monitoring well data was the Theis Equation (1935) for a confined aquifer system. The Theis solution estimates transmissivity and storativity of a pumped aquifer. The assumptions associated with the Theis solution are the following:

a. Aquifer has infinite areal extent
b. Aquifer is homogeneous, isotropic and of uniform thickness
c. Pumping well is fully penetrating
d. Flow to pumping well is horizontal when pumping well is fully penetrating
e. Aquifer is confined
f. Flow is unsteady
g. Water is released instantaneously from storage with decline of hydraulic head
h. Diameter of pumping well is very small so that storage in the well can be neglected

In order to apply the Theis solution to the water level analysis for this project, additional assumptions needed to be addressed: 1) Injection can be treated as pumping in AQTESOLV by changing the sign of the water level displacements and 2) deviations from the assumptions of the Theis method do not significantly affect the analysis.

4.2.4.1 Analysis of INEL-D Well Data

Well INEL-D is located 2000 feet to the west of well UI#2 at the UIGFL (Figure 3.6). Figure 4.6 presents the water level data for INEL-D for the period January 23, 2006 to April 17, 2006.

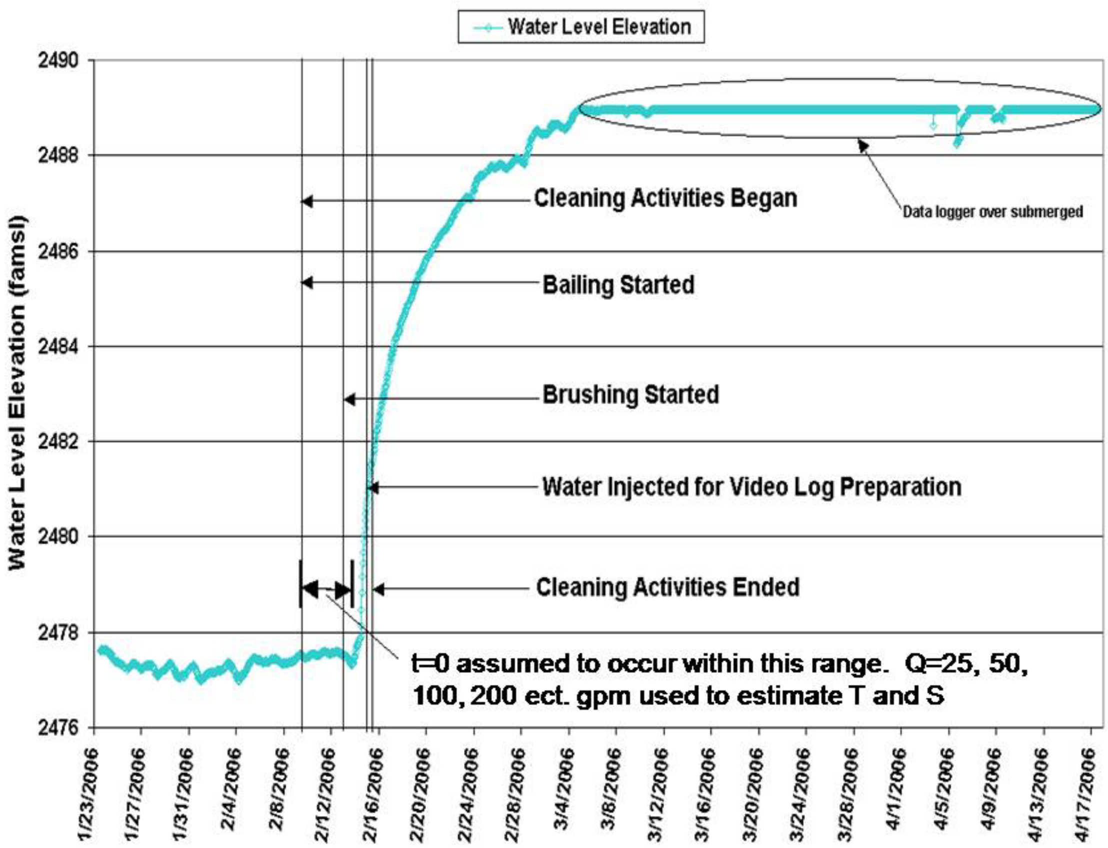

Figure 4. 6 Arithmetic plot of hourly water level elevations data for the period 01/23//2006 to 04/17/2006 for well INEL-D. Bailing started at approximately 08:15 hours on 02/10/2006. Brushing began at approximately 07:00 hours on 02/13/2006. Water was poured down UI2 from approximately 10:00 hours to 13:00 hours on 02/15/2006. All cleaning and video logging operations ended at 17:00 hours on 02/15/2006. .

Water levels in well INEL-D began to rise at 11:00 hours on 02/14/2006. The initial water level elevation was 2477.90 famsl. In order to evaluate whether the water level rise in INEL-D well was due to cleaning activities in well UI#2 and not due to other influences such as city of Moscow pumping activities, a hypothetical, conceptual, injection well model was tested by trial-and-error type curve fitting in AQTESOLV. One assumption of the conceptual model was that the flow rate down the UI#2 borehole and into the Vantage sediments began during the morning of February 14, 2006 between 07:00 hours and 11:00 hours. During this time, pieces of casing were bailed out of the well, and thus it was assumed that well cleaning activities at this time caused a significant increase in the rate of water flow out of the bottom of well UI#2 (i.e., injection). Coincidentally, water levels in well INEL-D began to rise at approximately 11:00 hours on February 14, 2006. INEL-D water level data were analyzed by using the Theis solution for a confined aquifer system in AQTESOLV with a two-hour lag time. A two-hour lag time placed the time when injection began at 09:00 hours on February 14, 2006. The aquifer thickness in AQTESOLV was set at 225 ft, and well UI#2 was considered to be fully penetrating. The injection rate (Q in gpm) was estimated by trial-and-error for a range of T and S values. An acceptable estimate for the storage coefficient of the Wanapum aquifer system is 1×10^{-4} (Osiensky, 2007). Transmissivity estimates were based on an aquifer thickness (b) of 225 ft, and a reasonable K (hydraulic conductivity) value for fine-to-medium size grain sands that are present within the Vantage interval penetrated by well UI#2. The transmissivity estimate was based on T=Kb. These values for T and S established the limits that controlled the range of possible injection rates while manually matching the type curve for the Theis solution to the displacement data (i.e., inverse of drawdown) for well INEL-D. The type curve match to the INEL-D displacement data was used to provide a method to test the "reasonableness" of the conceptual, injection well model (Figure 4.7).

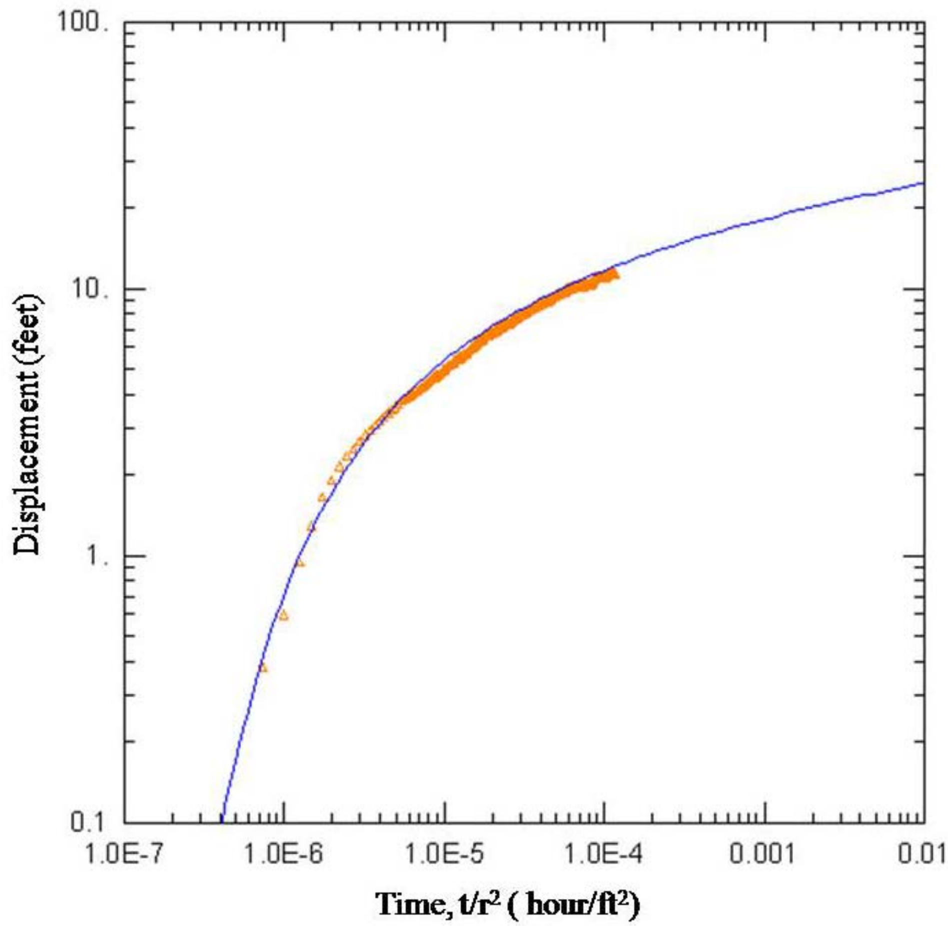

Figure 4. 7 Log-log plot of water level displacement versus t/r^2 for well INEL-D showing the Theis type curve match to the data. The orange colored points are the measured displacement data. The blue colored line is the Theis type curve.

The Theis type curve match shown in Figure 4.7 yields on injection rate of 112.2 gpm, a T value equal to 637 ft^2/day, and an S value of 1.56 x 10^{-6}. This match yielded a storage coefficient of 1.56x10^{-6}, which is two orders of magnitude lower than the high range of S estimated for the basin. During trial-and-error matching, the T and S values for the aquifer were held constant while a range of injection rates were input into AQTESOLV. No acceptable Theis type curve match could be made for the range of input injection rates (Q) for the original estimated S value. Therefore, it is concluded based on the hypothetical, conceptual, injection well model that cleaning activities in UI#2 did not cause the water level rises measured in well INEL-D.

4.2.4.2 Water Level Rise in D19D Well

Well D19D is completed into the lower part of the Lolo flow of the Wanapum Formation, and is 2190 feet to the west of the well UI#2. Figure 4.8 is a plot of water level elevations for well D19D over the time period from 01/23/2006 to 04/17/2006.

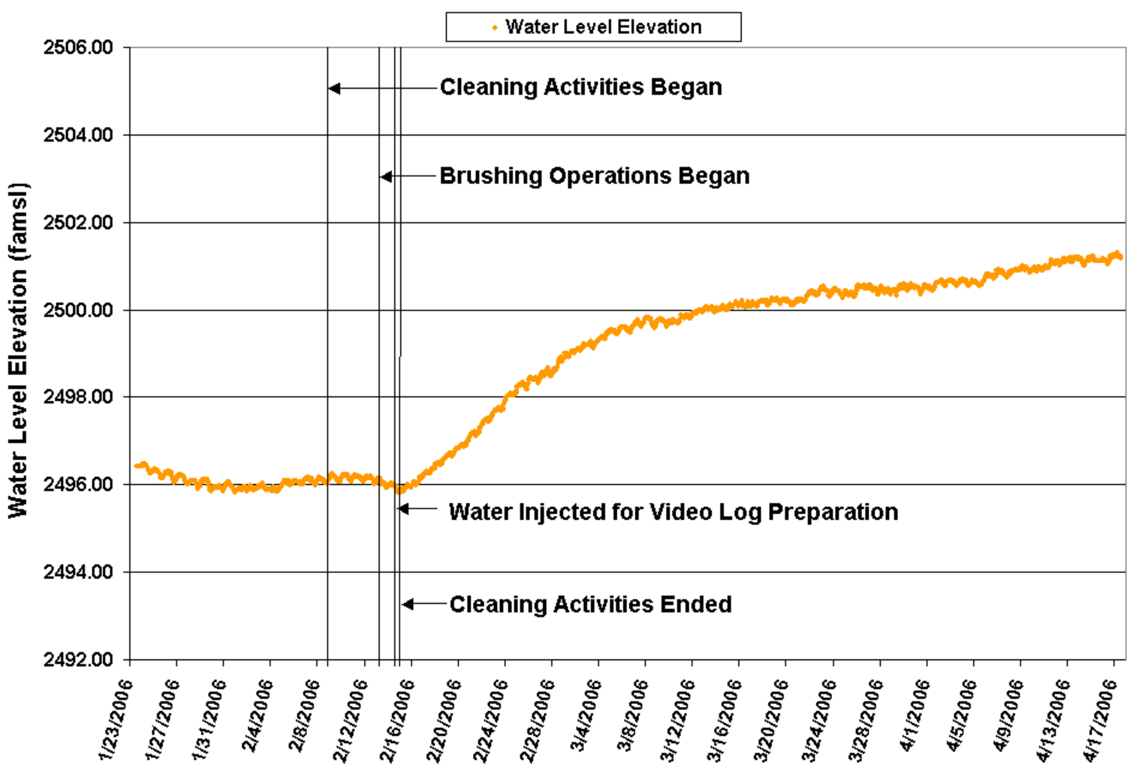

Figure 4. 8 Arithmetic plot of hourly water level elevations from 01/23/2006 to 04/17/2006 for well D19D. Several thousand gallons of water were poured down UI2 from approximately 10:00 hours to 13:00 hours on 02/15/2006. All cleaning and video logging operations ended at 17:00 hours on 02/15/2006.

Water levels in well D19D began to rise at 17:00 hours on 02/15/2006. The initial water level elevation was 2496 famsl. The water levels in local monitoring wells are difficult to compare directly because of the different completion zones of the wells combined with the steep downward gradient between the sediments of Bovill and the Vantage sediments. The rise of water levels in well D19D originally was assumed to be the result of cleaning activities in well UI#2. However, as described later in section 4.2.4.4, the water level rises are believed to represent a recharge pulse from Paradise Creek.

4.2.4.3 *Water Level Rise in Appaloosa Horse Club Well*

The third well in the monitoring network that experienced a period of rising water levels that coincided with cleaning UI2 is the Appaloosa Horse Club well. The AHC well is completed in the lower Wanapum Formation and is located 5300 ft west of well UI#2. Figure 4.9 is a plot of water level elevations for the AHC well for the time period 01/23/2006 to 04/17/2006.

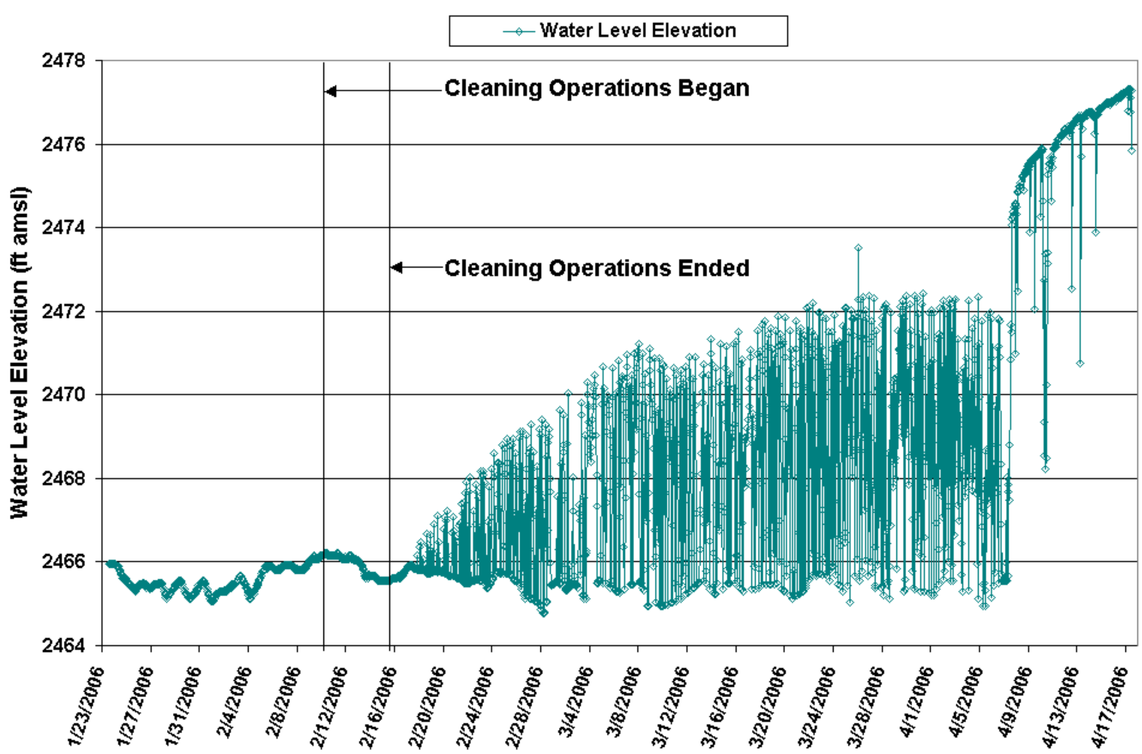

Figure 4. 9 Arithmetic plot of hourly water level elevations for the period 01/23/2006 to 04/17/2006 for Appaloosa Horse Club well. All cleaning and video logging activities in well UI#2 ended at 17:00 hours on 02/15/2006.

Water levels in the AHC well began to rise at 13:00 hours on 02/16/2006. Superimposed on the rising water levels were the effects of sporadic pumping in the AHC well itself. The AHC well pumps at a rate of about 100 gpm for short time periods, and rapid drawdowns are apparent as spikes in the data plot. From the time when injection of water into well UI#2 is assumed to have begun there was a lag time of 53 hours until water levels began to rise in the AHC well. However, as described in the section below, the water level rises are believed to represent a recharge pulse from Paradise Creek.

4.2.4.4 Evaluation of Recharge Pulse from Paradise Creek.

A semilog plot of displacement versus distance for wells INEL-D, D19D, and AHC (Figure 4.10) shows that the water level rises measured in wells AHC and D19D are not consistent with the water level rise measured in well INEL-D based on the conceptual model of well UI#2 as an injection well.

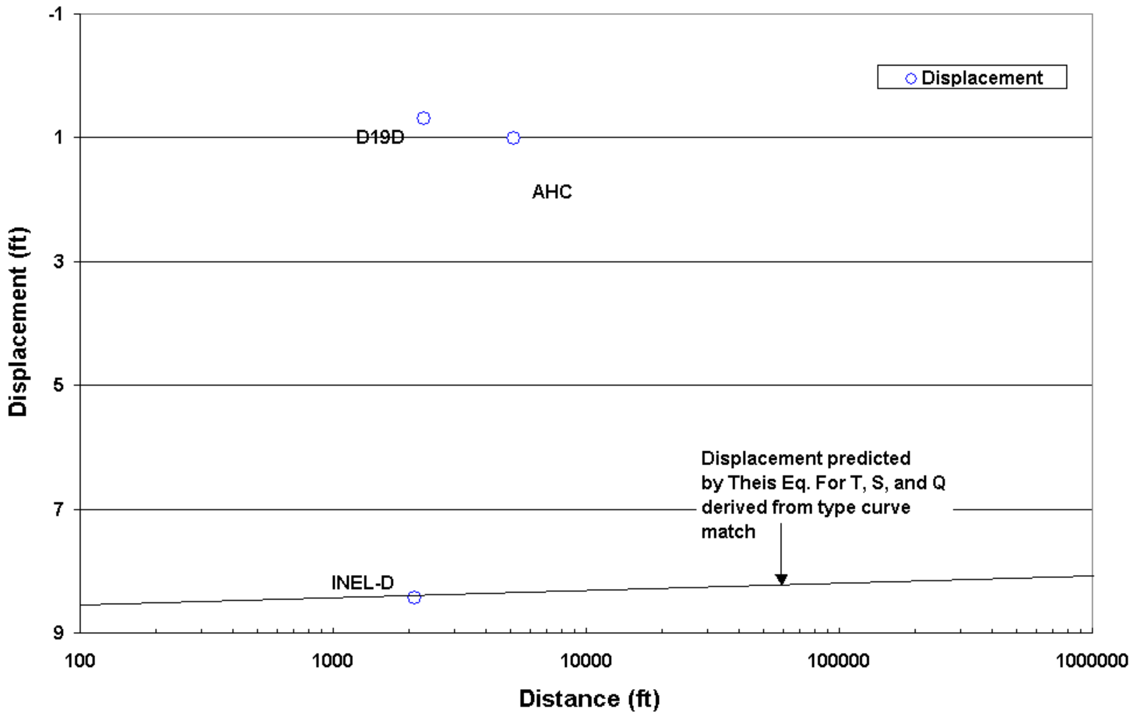

Figure 4. 10 Semilog plot of predicted displacement versus distance from well UI#2 for time equal to 10 days after cleaning activities began in well U#2. Displacements for well INEL-D, D19D, and AHC are actual measured values for time = 10 days.

Figure 4.10 clearly shows that the displacements measured in wells D19D and AHC do not fit the theoretical model for the displacement predicted by the Theis Eq. (Figure 4.7) for those locations. Figure 4.11 compares the water level elevations for these wells on February 10, 2006 immediately prior to cleaning and on February 25, 2006, ten days after cleaning activities ended.

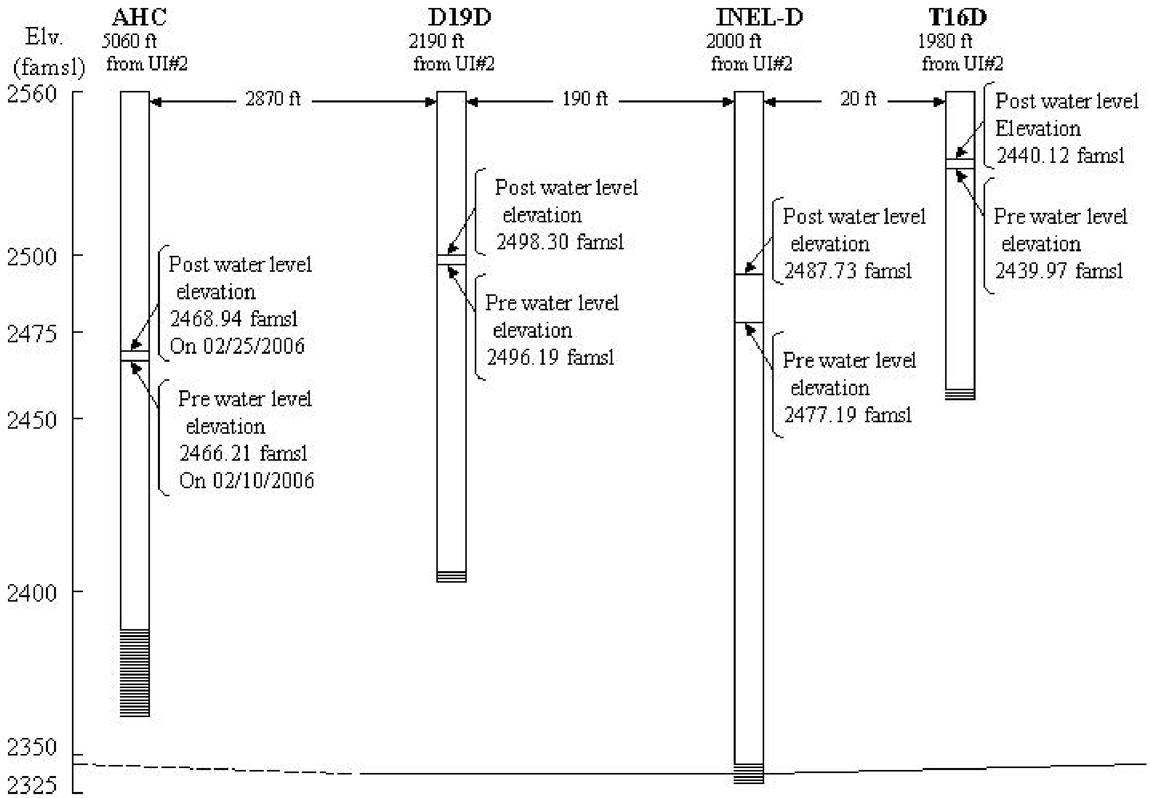

Figure 4. 11 Distribution of water level rises in monitoring wells AHC, D19D, INEL-D, and T16D.

This figure shows that water levels rose fairly uniformly over the entire area, and that the magnitude of the water level rises in individual wells was not a function of radial distance from well UI#2 as would be expected if well UI#2 was the source of the water (i.e., injection well). Another line of evidence against well UI#2 being the source for the water level rises is illustrated in Figure 4.12.

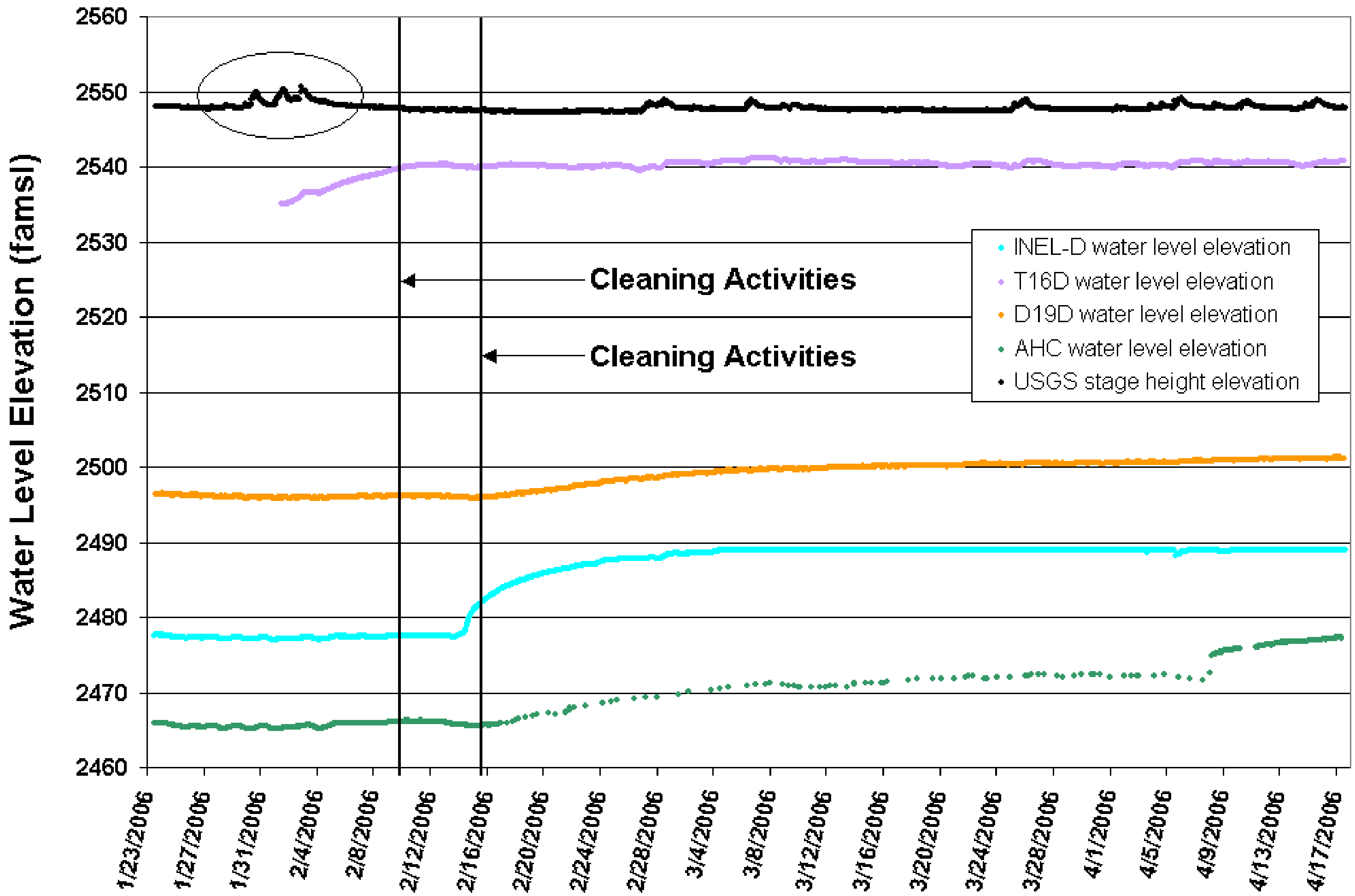

Figure 4. 12 Arithmetic plot of hourly water level elevations for the period 02/23/2006 to 04/17/2006 for all monitored wells at the UIGFL, and the AHC well.

This figure shows that water levels began rising in well T16D eight days prior to the start of cleaning activities in well UI#2. This period of increasing water levels coincides closely (i.e., short lag time) with a period of increased flow in Paradise Creek between January 30, 2006 and February 3, 2006. Therefore, while the rising water level trends in wells INEL-D, D19D, and AHC appear to be related to cleaning activities in well UI#2, the rising trends most likely were purely coincidental and, actually caused by a ground water recharge event from Paradise Creek.

Figure 4.13 is a plot of water temperatures for T6, and wells T16D and D19D for the period 02/01/2006 to 03/03/2006.

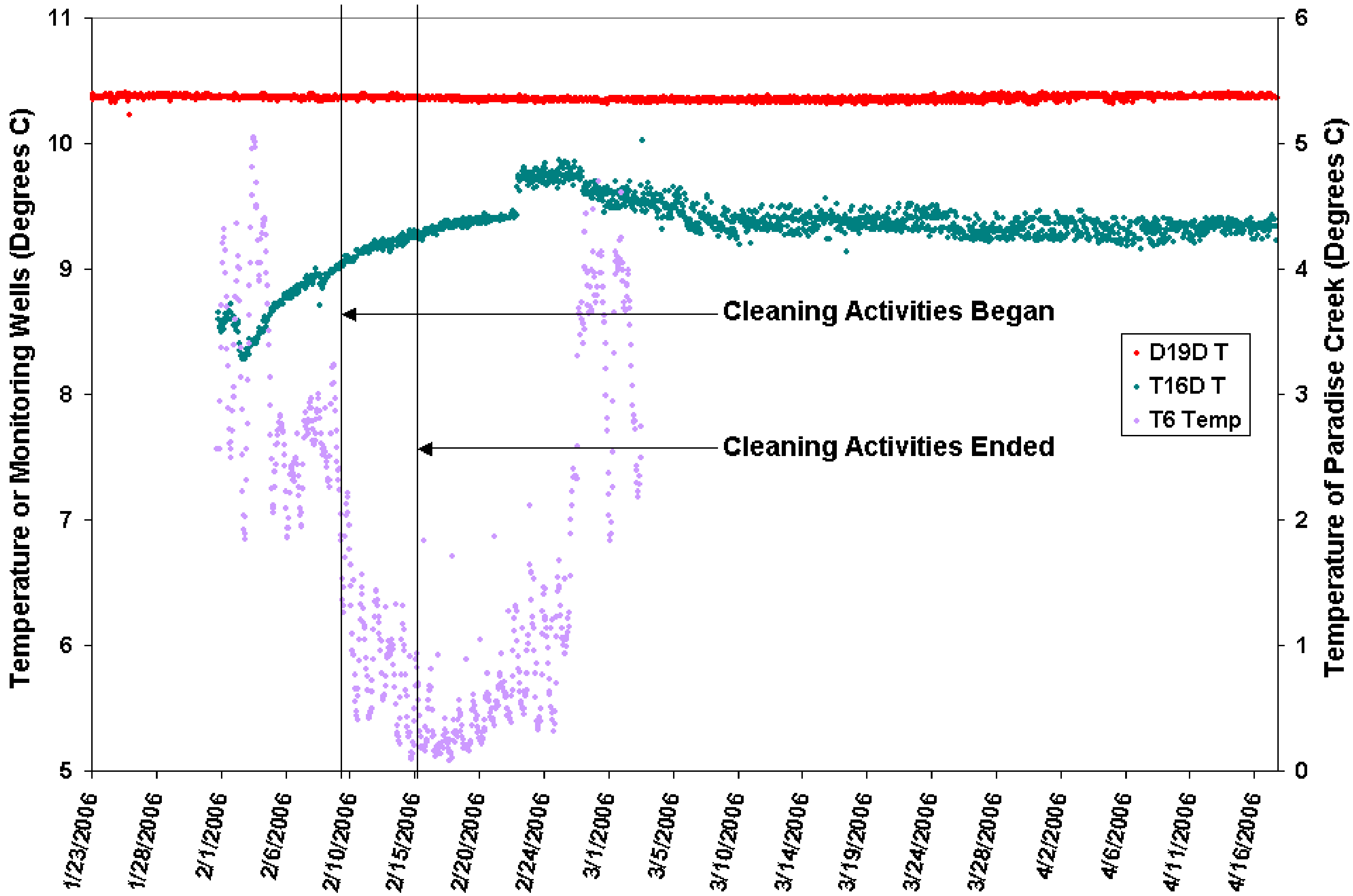

Figure 4. 13 Arithmetic plot of water temperatures in wells T16D and D19D, and in Paradise Creek at measurement location T6.

The relatively cool ground water temperatures measured for well T16D prior to the start of cleaning activities in well UI#2 are consistent with the rising water level trend in T16D over this period. In addition, the cool ground water temperatures in T16D during this time period clearly reflect the cool winter time water temperatures in Paradise Creek. The ground water temperatures in D19D were not affected by the influx of Paradise Creek water because the depth of D19D is 63.94 ft greater the T16D. However, the rising water levels (Figure 4.12) in wells D19D, INEL-D, and AHC were caused by pressure changes due to the influx of Paradise Creek water into the upper portion of the Lolo basalt. Transmission of the pressure changes to the deeper portion of the Lolo flow took several days. This caused the rising water level trends in wells D19D, INEL-D, and AHC to lag behind the rising water levels in T16D. Therefore, it can be concluded that the rising water level trends in the wells, D19D, INEL-D, and AHC were due to recharge from Paradise Creek over the period of higher stream flow (between 01/30/2006 and 02/07/2006) before cleaning activities started in well UI#2.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The chapter present conclusions and recommendations derived over the course of this thesis research. The conclusions are derived from information contained in previous investigations, and the data collected and analyzed during this investigation.

5.2 Affect of Cleaning on Flow in Well UI#2 Borehole

The affect of cleaning and development of well UI#2 did not permanently change the vertical downward flow in the borehole. The removal of accumulated sediments did not make a significant difference by allowing more water to flow into the borehole from the Wanapum basalt and out in to the Vantage sediments. The vertical downward flow in the borehole is merely the natural vertical gradient that already existed between the Wanapum basalt and the Vantage sediments prior to the well cleaning. The fluctuating water levels measured during cleaning were the affects of brushing and bailing. The change in flow, whether an increase or a decrease in flow, only occurred during cleaning activities and returned to baseline (i.e., precleaning) shortly after cleaning activities ended.

5.3 Affects of Well UI#2 Cleaning on the Ground Water Flow System in the Sediments of Bovill

No permanent changes were observed in the monitored water levels in the sediments of Bovill as a result of cleaning and development in well UI#2. A cone of depression did not develop in the sediments of Bovill, and cause the “dip” in water levels measured during cleaning activities. The change in ground water temperatures measured after cleaning began was a result of the same unidentified process that affected ground water temperatures in all of the Paradise Creek monitoring well simultaneously seven days after cleaning ended.

5.4 Affects of Well UI#2 Cleaning on the Ground Water Flow System in the Wanapum Basalt and Vantage Sediments

Cleaning of well UI#2 did not affect monitored water levels in the Lolo basalt or the Vantage sediments underlying the UIGFL. The observed water level rises in the UIGFL monitoring wells were merely coincidental with well UI#2 cleaning activities. The water level rises in monitoring wells at the UIGFL were the result of a ground water recharge event from Paradise Creek. The five-day spike in stream stage of Paradise Creek prior to cleaning caused the water level rise in monitoring wells at the UIGFL.

The implication of this recharge observation, suggests strongly that the UIGFL is one area where the Wanapum aquifer system is recharged annually during periods of high flow in Paradise Creek. Precipitation events in the Palouse Basin could potentially be “harvested” for recharging ground water storage depleted over the drier periods of the year.

5.5 Recommendations

The following recommendations are intended for future work that could aid in further understanding of the findings from this project. The recommendations are organized in the order that the analyses were discussed during this project.

Visual dye tracer tests could be designed based on the information collected from the warm water tracer tests. Implementation of visual dye tracer tests could be successful by applying the information given in Appendix-A concerning the complex circulation patterns that are present in well UI#2 borehole.

The transducer (T6) that was placed in the thalweg of Paradise Creek collected valid data for this investigation. For future work involving monitoring temperature and water level in Paradise Creek adjacent to well UI#2, a permanent apparatus should be installed.

Stress well UI#2 under hydraulic pumping conditions. A better understanding of the hydraulic connection between the Lolo basalt and sediments of Bovill in this area would be useful. A large enough capacity pump placed in UI#2 could affect the ground water flow environment in the vicinity of UI#2 where Paradise Creek flow would be affected.

Conduct an isotope study to understand the migration of Paradise Creek water into the underlying aquifer system. This study should incorporate additional wells and the monitoring wells used in this study for ground water sampling points. This type of investigation would answer many questions about the residence time of Paradise Creek water that is recharging the Wanapum aquifer system.

Further monitoring used in this project and including well INEL-S would provide more information about the migration of recharge pulse pressure transients, and rates of water movement from Paradise Creek into the underlying aquifer systems.

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APPENDIX A

WELL UI#2 TRACER TESTS

METHODOLOGY OF WELL UI#2 TRACER TESTS

Three types of tracer tests were conducted to characterize the circulation environment in well UI#2. Several different tracers were used and applied at different points in well UI#2. Salt water, warm water, and dry ice tracers were applied from land surface. Warm water also was injected at specific depths below land surface.

A-1.1 Land Surface Tracer Tests

Each LS tracer test was conducted by pouring warm water or saltwater down well UI#2 from land surface. Data loggers were suspended at 55, 100, 150, 194 and 196 fbls (Figure A.1).

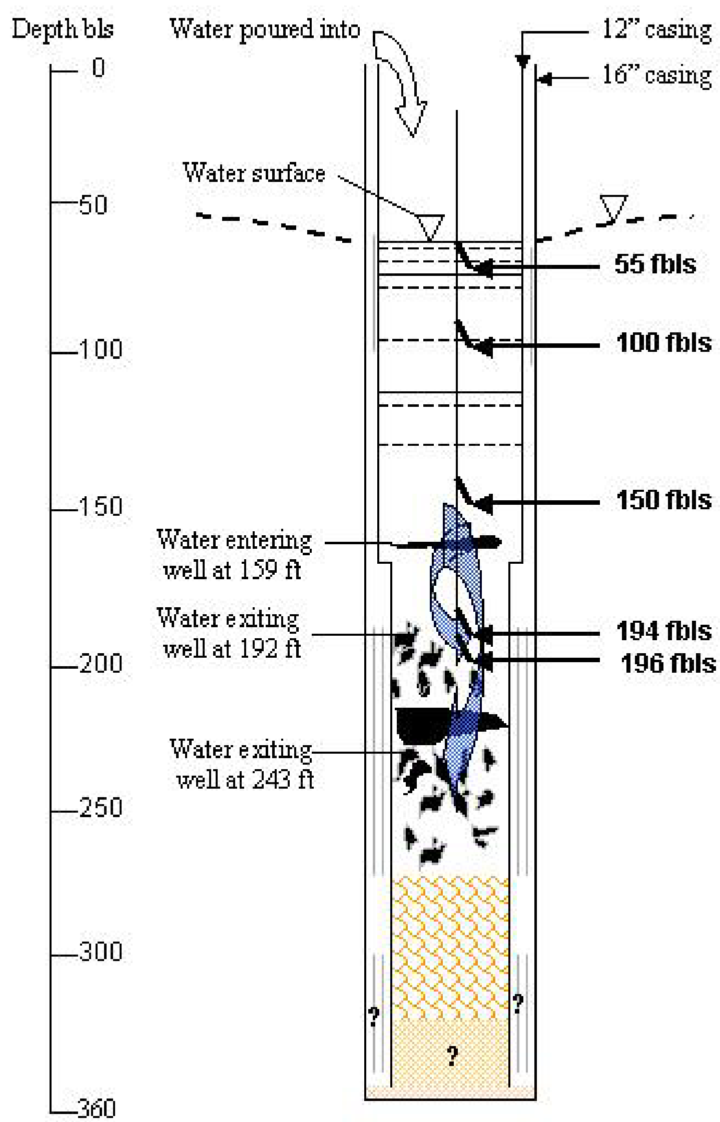

Figure A- 1 Schematic of Land Surface Tracer Design.

Each logger was programmed to measure on a one-second sampling frequency. The 55ft logger was placed to record the moment when warm water first contacted the water surface in the well.

A-1.2 Land Surface Tracer Test 1

Warm water was used as the tracer for the first tracer test conducted on June 6, 2006. The static water level in the well was 54.00 fbls. The data loggers were set to begin recording just before being lowered into the well. Six gallons of water at a temperature of 46.7 degrees Celsius was contained in a seven-gallon cooler. The cooler drain was modified to accept a ½ inch diameter nylon hose to convey the warm water into the borehole. The hose was needed to direct the warm water stream to the center of the well bore allowing it to free fall 54 feet to the water surface in the well. Warm water flowed at an initial rate of 0.65 gallons per minute and decreased exponentially over time. The data loggers were removed three hours after the warm water was initially added. It was assumed that the system had returned to equilibrium after this time.

A-1.3 Land Surface Tracer Test 2

Salt (NaCl) water was used for the second tracer test conducted on July 12, 2006. The static water level was 53.90 fbls. A seven-gallon cooler was used to contain six gallons of salt water. The water was 13.4 degrees Celsius when the salt was added. The salt-water solution needed to be 6000 µS (microSiemens) or less to minimize density effects. Salt was added to the water in approximately one-ounce increments. The actual measured electrical conductivity was 4507.45 µS. There are minimal density effects by a solution that has a electrical conductivity of 6000 µS or less, being added to fresh water (Domenico and Schwartz, 1990). A Solinst model _ conductivity/temperature probe was fixed in the well at 153.9 feet below static water level. Before setting the probe in the well, it was calibrated with 10,000 µS standard. Saltwater was added to the well using the same cooler and hose design for Land Surface Tracer Test 1. Saltwater flowed at an initial rate of 0.65 gallons per minute and decreased exponentially over time. Electrical conductivity values were recorded from the Solinst conductivity/temperature probe every two minutes starting initially when saltwater began to flow.

A-1.4 Point-Tracer (PT) Tests

The point-tracer tests were designed to apply warm water directly into the existing borehole circulation pattern in well UI#2. Data loggers were positioned below the injection point of the tracer to measure the temperature pulse as it migrated. For example, the length of time it took for the temperature changes to be measured between two data logger positions a set distance apart was used to estimate the velocity of the water flow in the well.

The Point-Tracer tests were conducted by injecting warm water contained in a polyethylene water tank at the land surface. For each test, the tank was filled at the UofI Wallace Complex with approximately 50-gallons of water at a temperature of about 46.4 ^{o}C. The tank was transported to the UI#2 pump house and connected to a length of one-inch diameter PVC pipe to inject the water into the well (Figure A-2).

A-1.5 Point-Tracer Test 1

The first Point-Tracer test injected warm water at a depth of 156 fbls; this design was named PT 156ft. The end of the tracer injection pipe was placed three feet above where water was seen in the post cleaning video log entering into well UI#2 (Figure A-3).

Figure A- 2 Photo of Point Tracer Test Set up on UI#2 Pump House. A pick up truck is backed up to UI2 pump house. A horizontal one-inch diameter PVC pipe is attached to tank containing warm water to convey the tracer to the well.

The tank was connected to the one-inch diameter PVC pipe by a slip-union coupling. A ball valve was used to control the flow injection rate. The flow rate was determined by measuring the time needed to fill a five-gallon bucket prior to each Point-Tracer test. Figure A-3 shows how the warm water was injected into the well UI2. Two different Point-Tracer tests were designed to inject the tracer at a different location in the well.

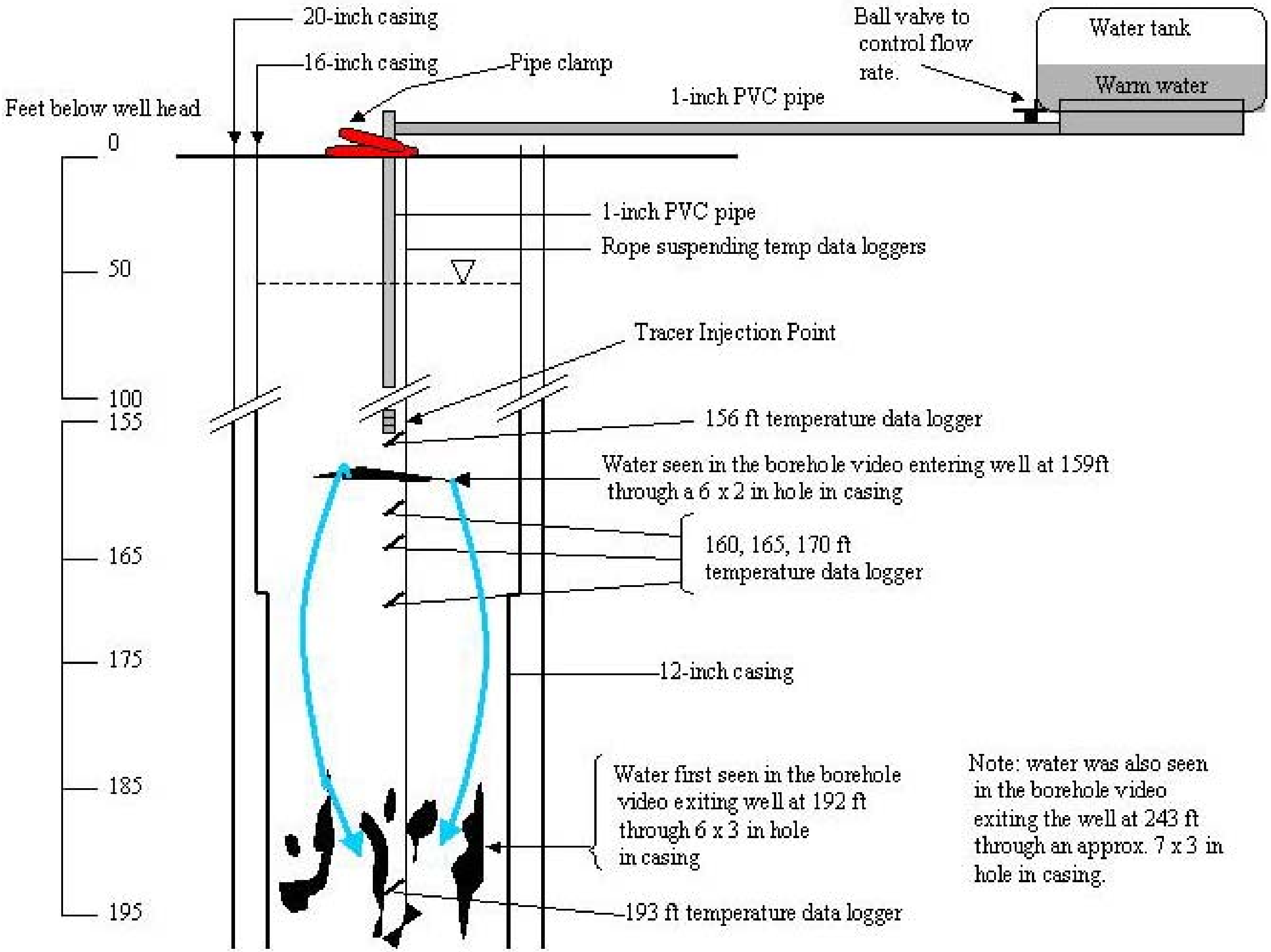

Figure A- 3 Schematic of warm water Point-Tracer 156ft test design.

The PT 156ft injection point was located three feet above the first crack in the 12" casing. The rationale for positioning the pipe at a depth of 156 feet was to apply the tracer near to the water entering the well through the crack in the casing.

A vent was used to displace air once water began flowing from the water tank through the horizontal and vertical PVC pipes. The bottom end of the vertical 1" PVC pipe was capped and perforated over a one-foot interval. The end was capped to control the velocity of warm water that flowed out of the end of the PVC pipe. The perforations allowed the water to flow horizontal and radially out into the borehole flow environment. Data loggers were suspended on a rope in the well along the vertical PVC pipe. A majority of the Point-Tracer tests had data loggers set on one-second sampling intervals except where noted for individual tests. The data loggers were suspended at depths of 156ft, 160ft, 165ft 170ft, and 193ft.

The 156ft logger was placed directly at the point were warm water was injected into the well. This logger position served to measure the temperature of the tracer as it entered the well environment, and the temperature decay with time.

The 193ft data logger was positioned one foot below where water was observed in the borehole video to be flowing out of the well. The purpose of this logger was to measure water temperature changes to this depth in the borehole. The data were used to calculate the velocity of water flow at this depth.

Each test was terminated when flow from the tank was less than 0.5 gpm. The flow of tracer was observed through the T-fitting vent. After flow was stopped, the data logger continued to record temperatures until their memory filled.

A-1.6 Point-Tracer Test 2

The second Point-Tracer test injected warm water at a depth of 160 fbls; this design was named PT 160ft. The reason for lowering the tracer injection point was to have the tracer applied directly into the flow path of water entering into the well.

From PT 156ft, the 156ft data logger was repositioned at 160 fbls, and the 160ft data logger was moved to 163 fbls. The 163ft logger enabled a finer scale of tracer temperature measurements. The thermal growth and decay of the introduced warm water tracer were monitored. Figure A-4 shows the repositioned PVC pipe and data loggers for Point-Tracer Test 2.

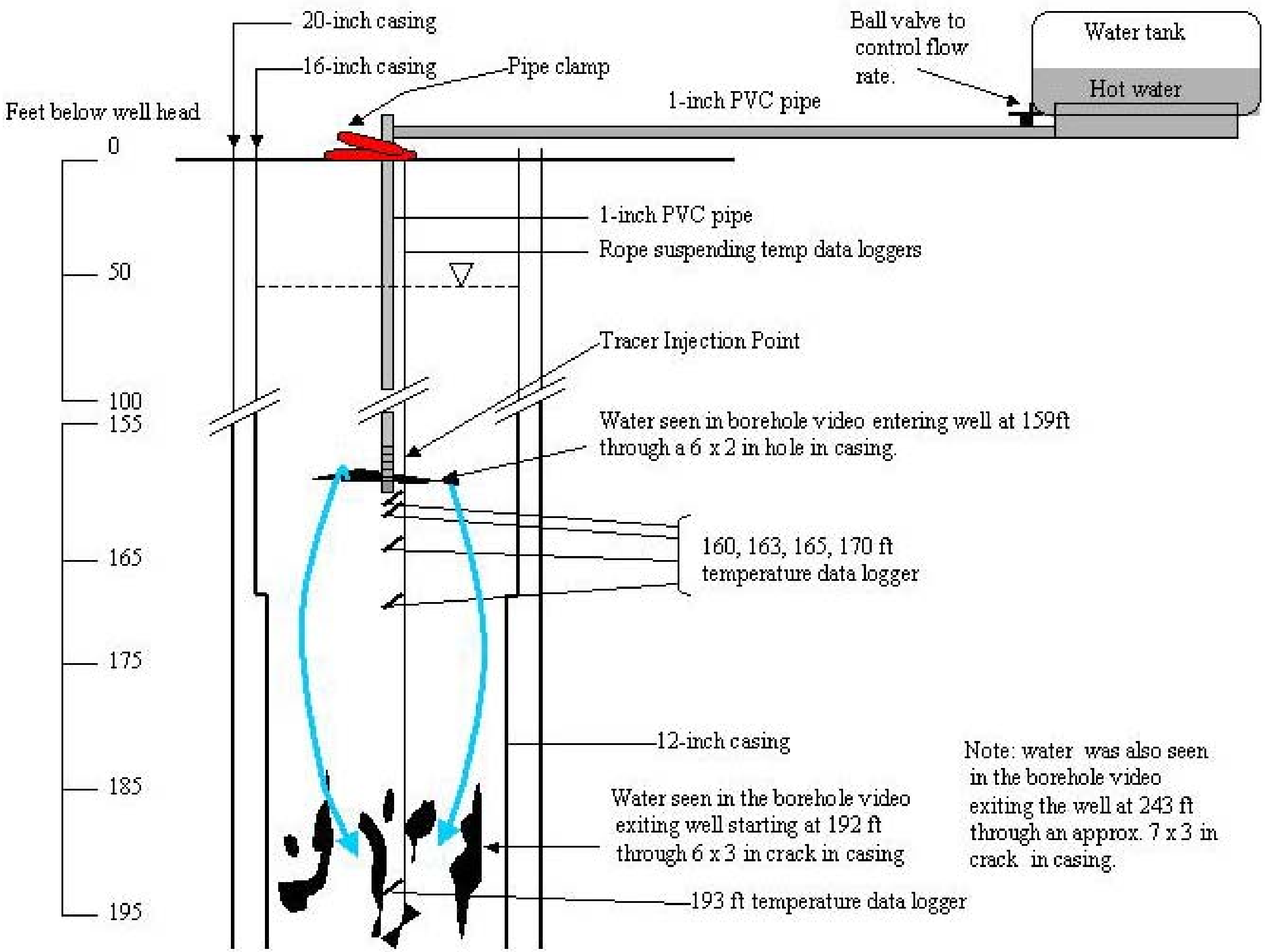

Figure A- 4 Schematic of Warm Water Point-Tracer 163ft Test Design.

A-1.7 Quantification of Water Flowing in well UI#2

The point-tracer tests were used to estimate the volume of water flowing per unit time in UI2. First, the flow velocity (v) was estimated as:

$$v = l/t \qquad \text{(Equation A-1)}$$

where: l is the distance between each data logger, and t is the time in seconds it took for a temperature change to occur from one data logger to the next. The volume per unit time or discharge Q was estimated from the velocity of the tracer in a water filled vertical pipe (i.e., well casing) as:

$$Q = (\pi\, r^2) * v \qquad \text{(Equation A-2)}$$

where: r is the radius of the steel well casing at the location of each data logger. Due to the complex well design of UI2 the discharge was estimated for both the 12” and 20” casings.

A-1.8 Land Surface Tracer Tests

Two LS tracer tests were conducted. Each test would attempt to characterize the borehole circulation from the depth of the water levels in well UI#2 to 192 ft.

A-1.9 Land Surface Tracer (LS) Test 1 Data

LS Test 1 was conducted on June 6, 2006. The data loggers were set and began recording background well water temperatures at 15:00 hours. Warm water tracer was applied at 15:01 hours. The warm water appeared to wet the sides of the casing as it free fell down to the static water level surface. Flow ended at 15:04:37. Figure A-5 is the plot of the temperature measured over the duration of the test.

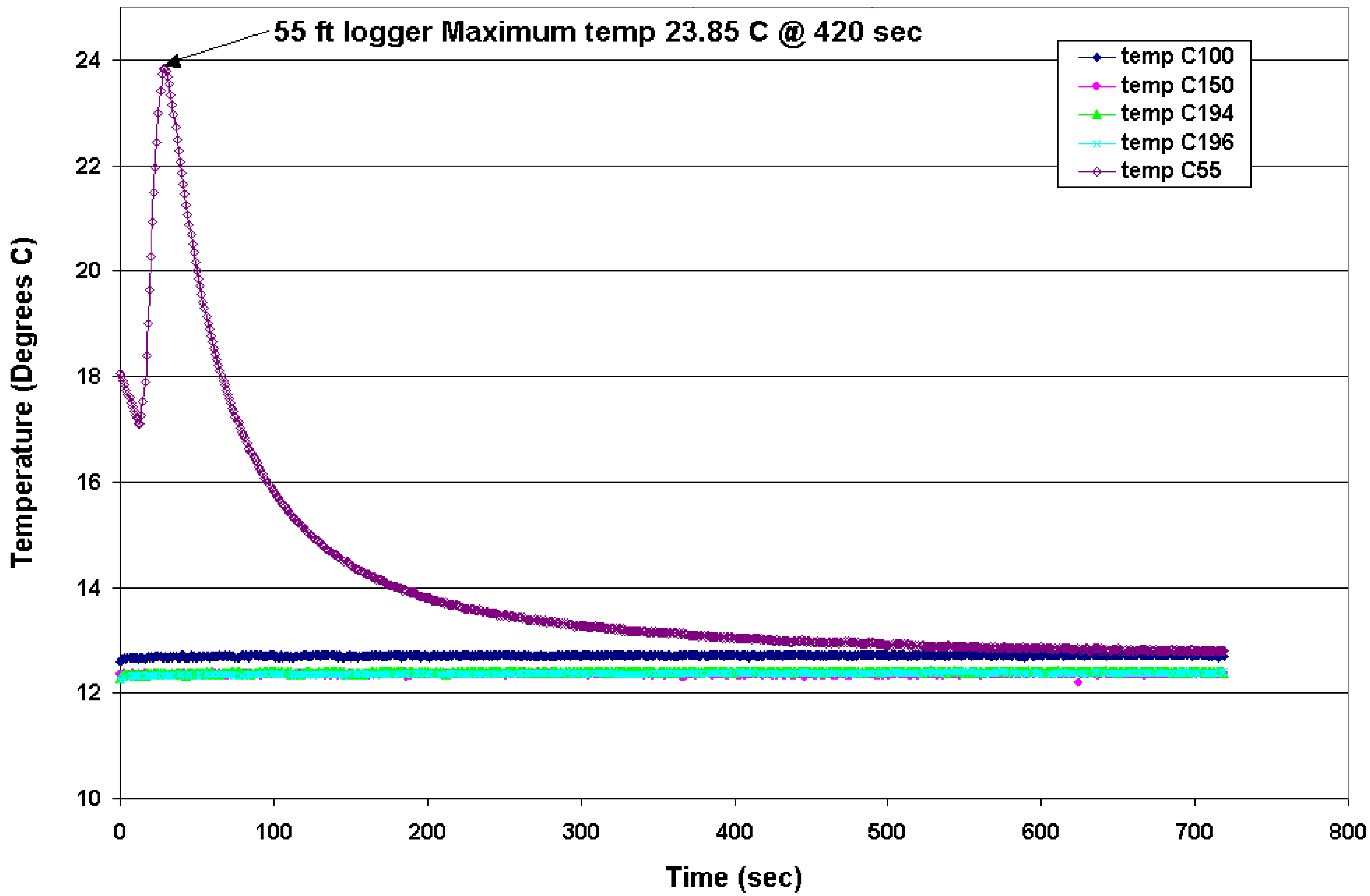

Figure A- 5 Plot of temperatures measurements for Land Surface Tracer Test 1. Time t = 0 corresponds to June 6, 2006 at 15:00 hours. Measurements were taken on 15 second intervals.

The background temperature at the 55ft logger was not the true background temperature because before the test was run, tracer was applied into the well to test the functionality of the tracer applicator. Approximately 20 minutes was allowed for the well water to equilibrate before the actual test was run. The 20 minutes was not enough time and the 55ft logger recorded the residual temperature while background temperatures could be recorded before the test.

The increase and decrease of temperature recorded at the 55ft logger is a function of how the well water temperature is increasing as a result of the tracer being applied. Whether the pulse of tracer migrated downwards by the flow in the well is unknown because no other temperature logger recorded an increase in temperature from the tracer pulse.

The 55ft logger also recorded water level fluctuations over the duration of the tracer test. The depth to water was 54.3 fbls when the data loggers series was suspended in the well. Figure A-6 has the plot of water levels in well UI#2 as tracer was being applied at a rate of 0.7 gpm.

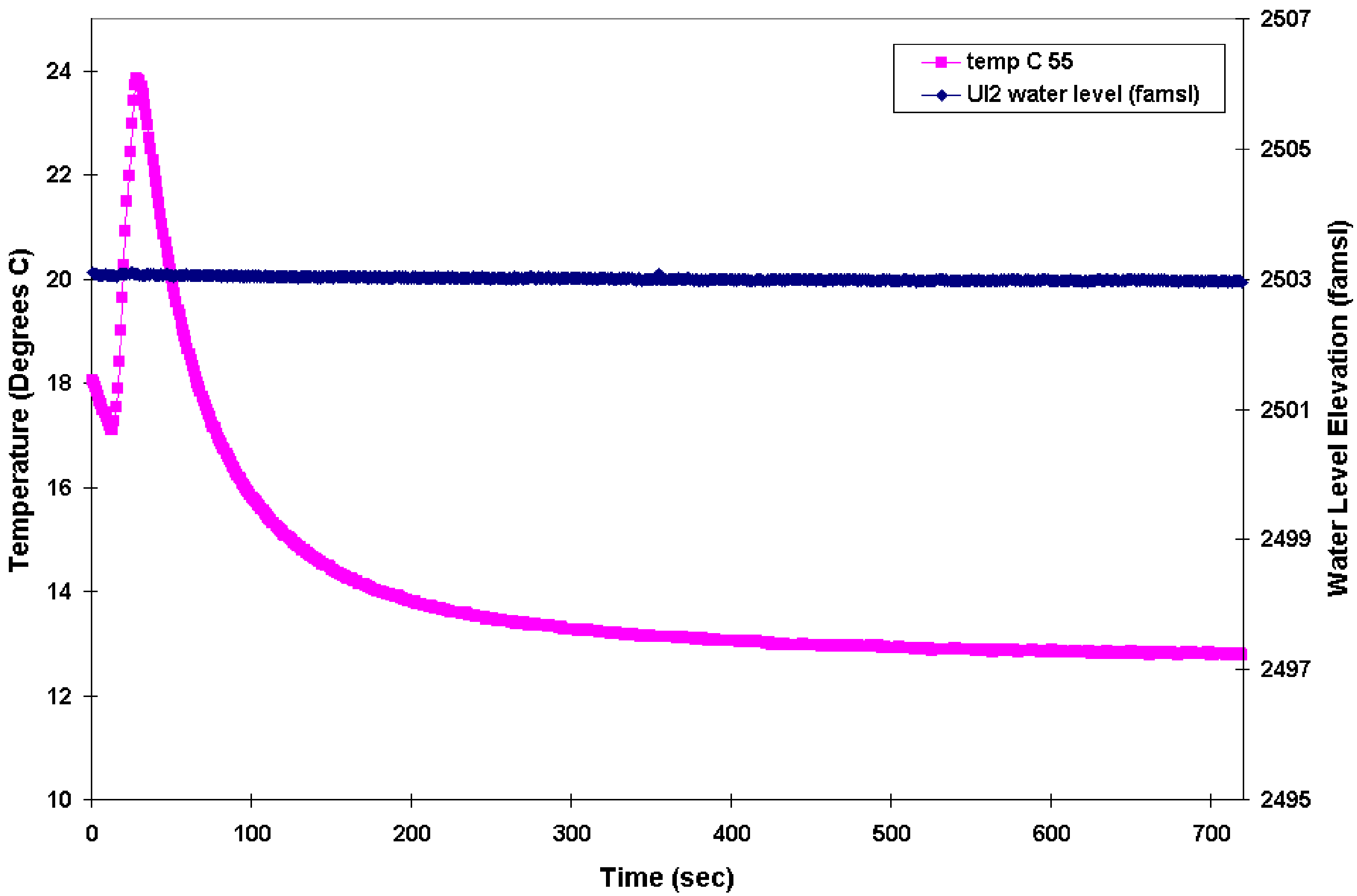

Figure A- 6 Plot of temperatures and water level elevation measurements during Land Surface Tracer Test 1. Time t = 0 corresponds to June 6, 2006 at 15:00 hours. Depth to water was 54.3 fbls. Measurements were taken on 15-second intervals.

The water level in the well rose by 0.02 ft while tracer was being poured down the borehole. The duration of rise was while water was being poured and equilibrated immediately.

A-1.10 Land Surface Tracer Test 2 Data

LS Test 2 was conducted on July 12, 2006. The static water level in UI2 was 53.9 fbls at 12:52 hours. Solinst conductivity/temperature probe was calibrated in 10,000 µS standard. The tracer conductivity was 4507.45 µS at 13.5 C. The probe was lowered to 100 feet below static water level and secured before the tracer was applied. The conductivity and temperature in well UI#2 was 714 µS and 11.9 C before the start of the test, respectively. The tracer was poured into the well at 17:00 hours at a rate of 0.7 gpm. A considerable amount of tracer wet the well casing as it fell the approximate 53 ft to static water level surface. Table A-1 is the conductivity and temperature values measured over the duration of the test.

Time	Electrical conductivity (mS)	Temperature (C)
17:07	268	12.72
17:09	269	12.72
17:10	269	12.72
17:11	269	12.72
17:12	268	12.72
17:14	268	12.72
Moved probe to 25 ft below static water level		
17:16	267	12.72
17:23	266	12.72

Table A- 1 Values of electrical conductivity and temperature for Land Surface Tracer Test 2. Two different point measurement depths recorded temperature and electrical conductivity below static water level in UI2 well during Land Surface Test 2

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A-1.11 Point-Tracer (PT) Tests

Two types of point-tracer tests were analyzed. PT 156ft was performed four times while PT 160ft had three runs. The first step in analysis will be to determine the arrival time of tracer at each data logger. The elapsed time that the tracer is measured between each consecutive logger will be used to determine an estimated flow velocity. The arrival time was selected from the temperature data when there was a sustained higher temperature from background or a constant increase in temperature measurements from background temperatures. Each of the following plots has 6.7 hours of temperature data plotted in second sampling intervals.

A-1.12 PT 156ft Test 1 Data

Point-Tracer Test 1 was conducted on July 27, 2006. Static water level in well UI#2 was 52.1 fbls. The data loggers started measuring at 11:45:00 hours. Injection of warm water tracer began at 11:46:00 hours with an injection rate of 2.6 gpm. The injection rate decreased exponentially and injection of warm water was terminated at 12:19:08 hours when it was less than 0.5 gpm. Static water level when data loggers were pulled was 52.11 fbls. Figure A-7 is a plot of temperature measurements over 6.7 hours.

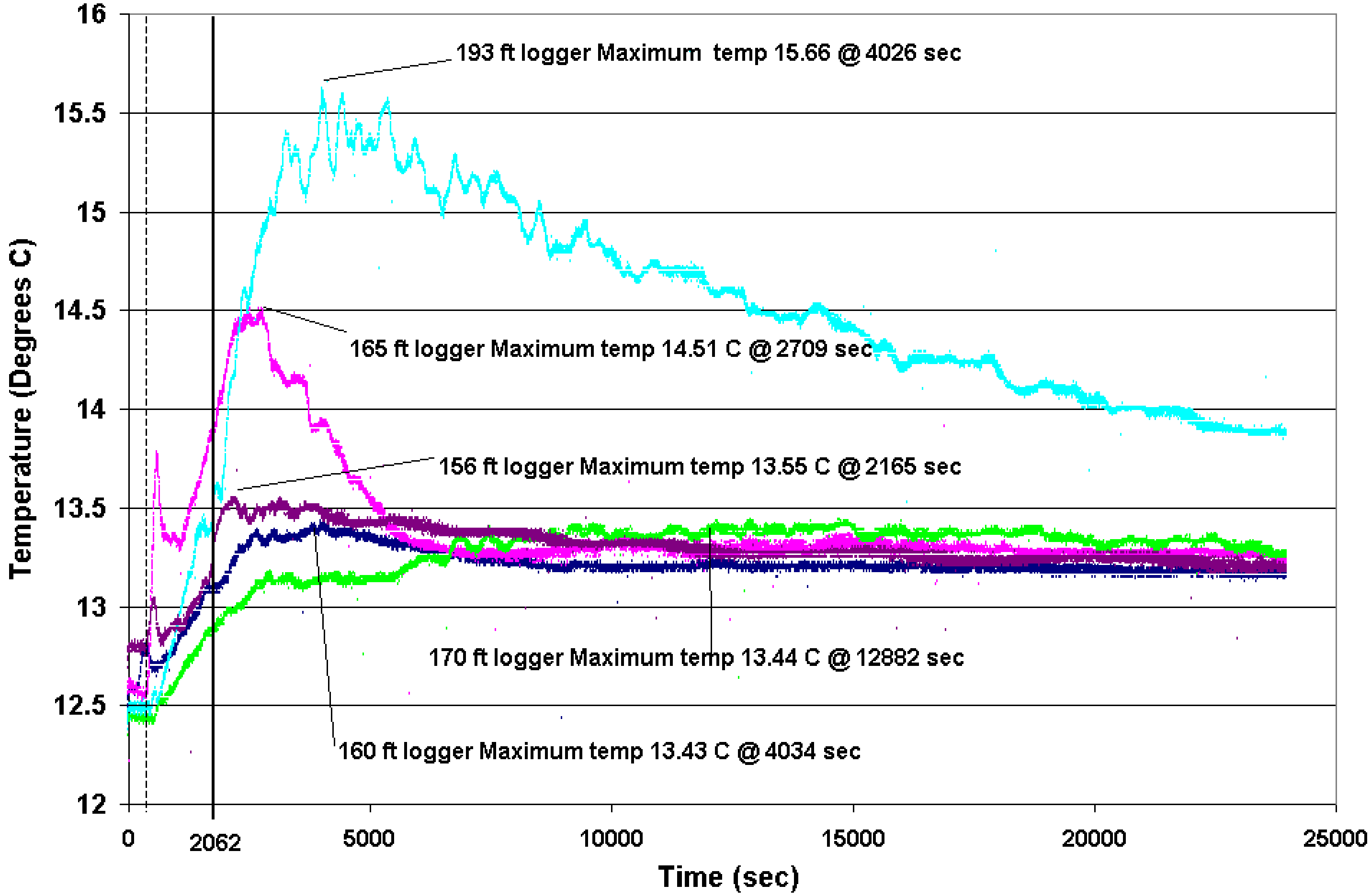

Figure A- 7 Plot of temperatures for Point-Tracer Test 1. PT Test 1 was conducted with an initial flow rate of 2.6 gallons per minute. Data were collected on a one second sampling interval. Time t=0 corresponds to when flow began. Flow ended at 2062 seconds after t=0. Dashed line at approximately 490 seconds is the discharge needed to be turned off momentarily for a tracer discharge pipe adjustment. Flow was terminated at 2062 seconds.

The first arrival time of tracer measured in each logger is in the follow Table A-2

Logger Depth (ft)	Arrival time from t=0 (sec)	Arrival Temp C	Peak Temp C	Peak Temp Arrival Time (2-sec)
156	401	12.81	13.55	2165
160	223	12.61	13.43	4034
165	424	12.61	14.51	2709
170	605	12.48	13.44	12882
193	518	12.55	15.66	4026

Table A- 2 First arrival times of warm water tracer at temperature loggers in well UI#2 during Point-Tracer Test 1.

The arrival times between the 160ft and 165ft would appear to show the conceptual order of how the design is intended to work. The upper and lower logger arrival times do not correspond to the intended design of the test. The disorder of arrival times may mean that the loggers were hung up on obstructions. The suspension rope may have become wrapped around the PVC pipe; this may have prevented proper setting of the series of data loggers while lowered into the well.

A-1.13 PT Test 2 Data

Point-Tracer Test 2 was conducted on July 31, 2006. The static water level was 52.4 fbls in UI2 well. Based on Test 1 results, the logger suspension rope was looped and hung differently for this test in an effort to help ensure accurate placement in the well. The data loggers were programmed to record on a two-second sampling frequency the lowered into the well. Data loggers recorded over six minutes and 18 seconds of background water temperature measurements before tracer was injected. Flow of tracer began at 12:25:26 hours with an injection rate of 1.25 gpm and decreased exponentially over a 56-minute period. Injection ended at 13:21:23 hours when flow was less that 0.5

gpm (Figure A-8). The water level in well UI#2 at the time when data loggers were pulled was 52.5 fbls.

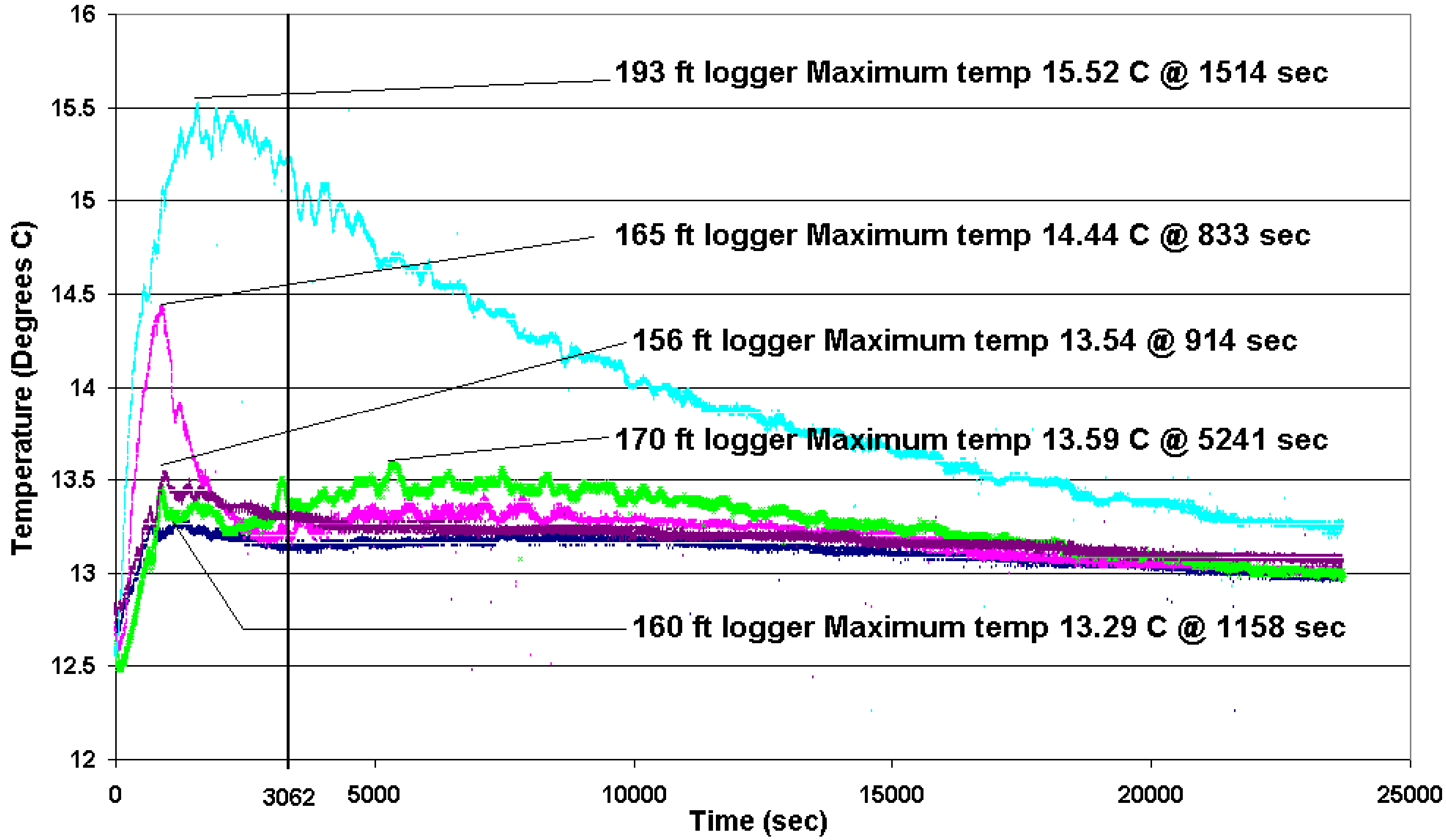

Figure A- 8 Plot of temperatures for Point-Tracer Test 2. PT Test 2 was conducted with a flow rate of 1.25 gallons per minute. Data were collected on a two second sampling interval. Time t=0 corresponds to the beginning of the injection. When flow began water temperature in tank was 45.8 C. Flow was terminated at 3062 seconds.

The times for first arrival for Point-Tracer Test 2 are presented in Table A-3.

Logger Depth (ft)	Arrival time from t=0 is start of flow (2-sec)	Arrival Temp C	Peak Temp C	Peak Temp Arrival Time (2-sec)
156	168	12.88	13.54	1514
160	148	12.81	13.29	5241
165	194	12.72	14.44	833
170	234	12.63	13.59	1158
193	80	12.78	15.52	914

Table A- 3 First arrival times of warm water tracer at temperature loggers in well UI#2 during Point-Tracer Test 2.

The arrival times for Point-Tracer Test 2 are in disarray similar to Test1. Although for this test, it appears that the 193ft logger may have been hung up and located closest to the PVC tracer pipe outlet.

Some possible obstructions that may cause the data logger or suspension rope to be hung up are metal casing barbs that maybe a result of brushing the casing during cleaning. In an attempt to lower the data loggers down without becoming hung up on obstructions, a spool of nylon rope was attached at the end. The spool was attached below the 193ft logger and duct taped to avoid the nylon becoming snagged on casing barbs. The spool was intended to weight the suspension rope and avoid it from swinging erratically about the inside casing area while lowering into position.

A-1.14 PT Test 3 Data

Point-Tracer Test 3 was conducted on August 2, 2006. The static water level was 52.1 fbls. Injection began at 11:13:44 hours at a rate of 1.25 gpm and decreased exponentially over the next 53 minutes. Flow was stopped at 12:06:14 hours. The water level at the time when data loggers were pulled was 52.3 fbls. Figure A-9 is a plot of the temperature measurements for Point-Tracer Test 3.

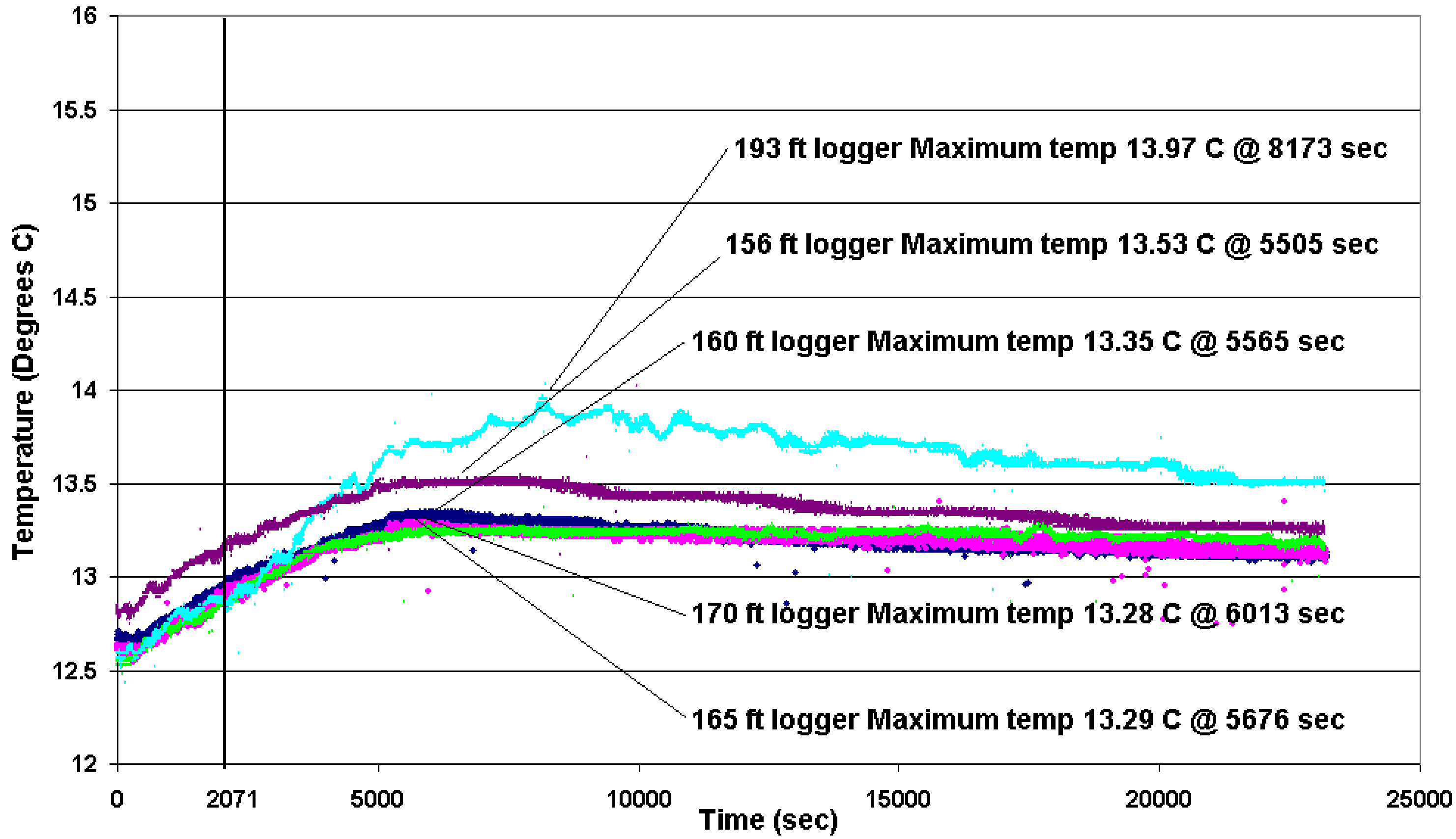

Figure A- 9 Plot of temperatures for Point-Tracer Test 3. PT Test 3 started with an injection rate of 1.25 gallons per minute. Data were collected on a one second sampling interval. Time t=0 corresponds to when flow began. Water temperature in tank at the start of flow was 46.4 C. After the completion of the test, the data loggers were retrieved from the well and were found to be tangled together.

The data loggers were found tangled together when retrieved from the well. The 165ft logger was hung up on the 160ft logger. From the plot of temperatures, it appears that all the loggers were tangled and suspended at approximately the same depth. All the data loggers have a tracer arrival time of approximately 500 seconds or 5.3 minutes.

A-1.15 PT Test 4 Data

Point-Tracer Test 4 was conducted on August 3, 2006. The water level was 54.15 fbls. The flow conditions for Point-Tracer Test 3 were reproduced fir this test. Approximately 20 minutes of background temperatures were recorded before the start of the test. Flow began at 15:30:15 hours with an injection rate of 1.25 gpm and decreased exponentially over time. Flow stopped at 16:20:51 hours. The water level at the time when data loggers were removed from well was 54.2 fbls. Figure A-10 is a plot of temperatures for Point-Tracer Test 4.

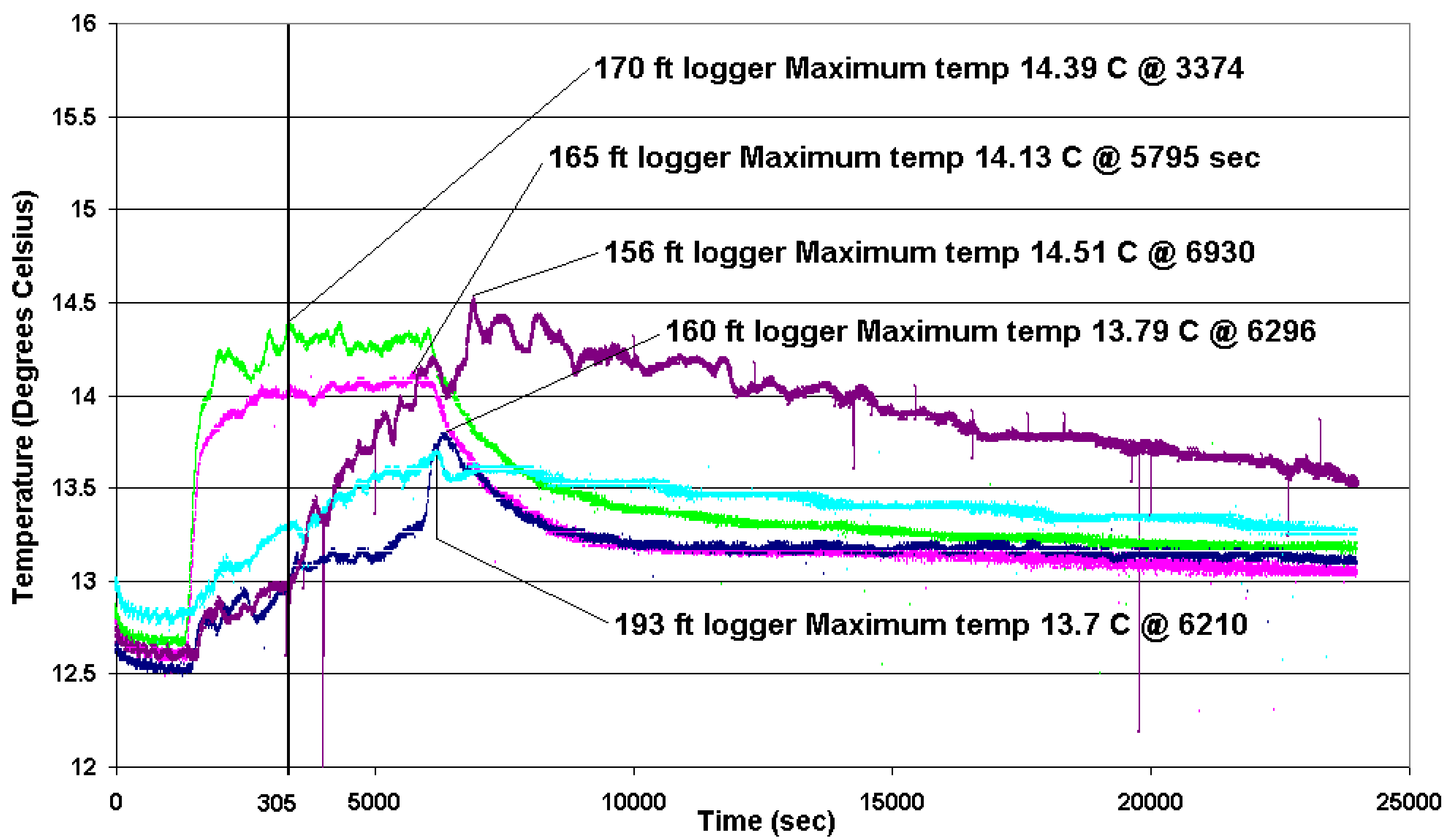

Figure A- 10 Plot of temperatures for Point-Tracer Test 4. PT Test 4 began with an injection rate of 1.25 gallons per minute. Data were collected on a one-second sampling interval. Time t=0 corresponds to when flow began. When flow began water temperature in tank was 45.9 C.

The first arrival times for Point-Tracer Test 4 are presented in Table A-4.

Logger Depth (ft)	Arrival time from t=0 is start of flow (2-sec)	Arrival Temp C	Peak Temp C	Peak Temp Arrival Time (2-sec)
156	380	12.63	14.51	6930
160	292	12.68	13.79	6296
165	177	12.65	14.13	5795
170	156	12.72	14.39	3374
193	333	12.87	13.7	6210

Table A- 4 First arrival times of warm water tracer at temperature loggers in well UI#2 during Point-Tracer Test 4.

The arrival times of test four do not follow the expected design of the Point-Tracer Test. The rapid rise in temperature recorded by the 170ft and 165ft loggers, maybe due their position relative to the tracer outlet. These two loggers have the first arrival times of over 100 seconds sooner that 160ft. The loggers may have been hung up when the suspension rope was set into position.

Based on problems encountered during Point-Tracer Tests 1, 2, and 4 it was concluded that the 156 ft data logger was not a good measurement location for the test. The arrival times measured for the 156ft logger are believed to be erroneous and due to heat from the tracer fluid warming up the well water environment to four feet above the outlet pipe.

A-1.16 PT Test 5 Data

Point-Tracer Test 5 was the first 160ft point-tracer test and was conducted on August 31, 2006. The data loggers were programmed on a one-second sampling frequency and set into the well. While setting the data loggers in the well, the last ten feet of suspension rope was not able to be set. The suspension system may have been hung up on obstructions in the well. The last ten feet were able to be set after jerking the suspension rope and feeling the full weight of the data loggers and rope.

Injection for Point-Tracer Test 5 began at 14:30:45 hours with an initial injection rate of 2.6 gpm. The injection rate decreased exponentially during the test until flow was stopped at 15:05:10 hours. Figure A-11 is the plot for temperatures measured during Point-Tracer Test 5.

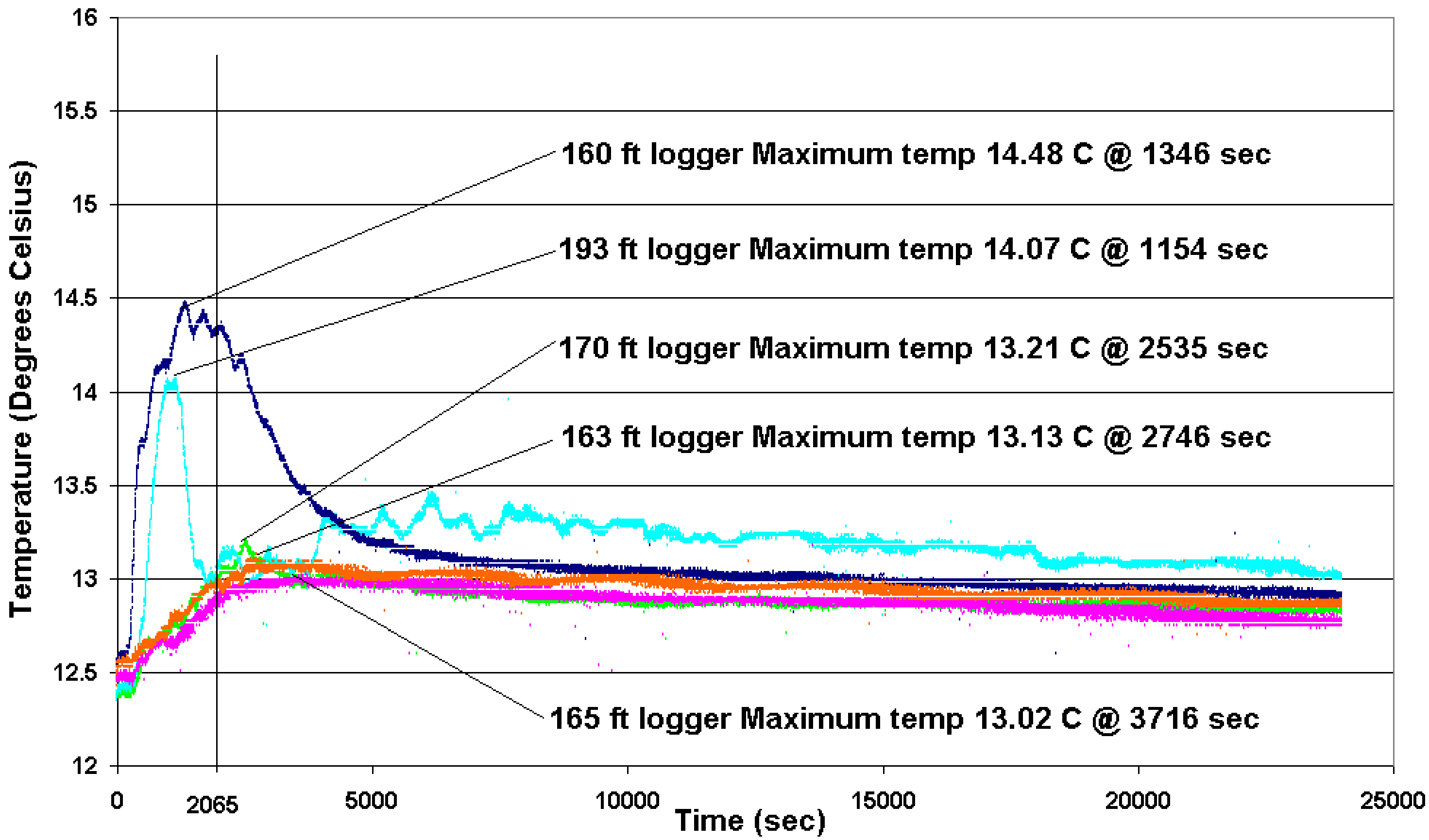

Figure A- 11 Plot of temperatures for Point-Tracer Test 5. PT Test 5 was conducted with an initial injection rate of 2.6 gallons per minute. Data were collected on a one-second sampling interval. Time t=0 corresponds to when flow began. When flow began water temperature in tank was 46.2 C.

The first arrival times for Point-Tracer Test 5 are presented in Table A-5.

Logger Depth (ft)	Arrival time from t=0 is start of flow (2-sec)	Arrival Temp C	Peak Temp C	Peak Temp Arrival Time (2-sec)
160	219	12.64	14.48	1346
163	294	12.58	13.13	2746
165	367	12.49	13.02	3716
170	435	12.5	13.21	2535
193	374	12.52	14.07	1154

Table A- 5 First arrival times of warm water tracer at temperature loggers in well UI#2 during Point-Tracer Test 5.

The arrival time of the tracer in the upper most four loggers appears to adhere to the conceptual design of the point tracer test. The hang up of loggers during lowering of the suspension line did not seem to affect the outcome of the test.

A-1.17 PT Test 6 Data

Point-Tracer Test 6 was conducted on September 2, 2006. The series of data loggers were programmed on a one-second sampling frequency and set into the well. Tracer-Test 6 was designed to partially duplicate Point-Tracer Test 5.

Two tracer pulses were injected during this test. The purpose was to observe how the system reacted to two pulses. The first pulse was injected for 2.53 minutes at an initial injection rate 2.6 gpm. The system was allowed three minutes to equilibrate. The second pulse began at 12:26:00 hours with an injection rate of less than 2.6 gpm. Injection rate decreased exponentially over time until flow was stopped at 12:57:10 hours. Figure A-12 is a plot of temperature measurements during Point-Tracer Test 6.

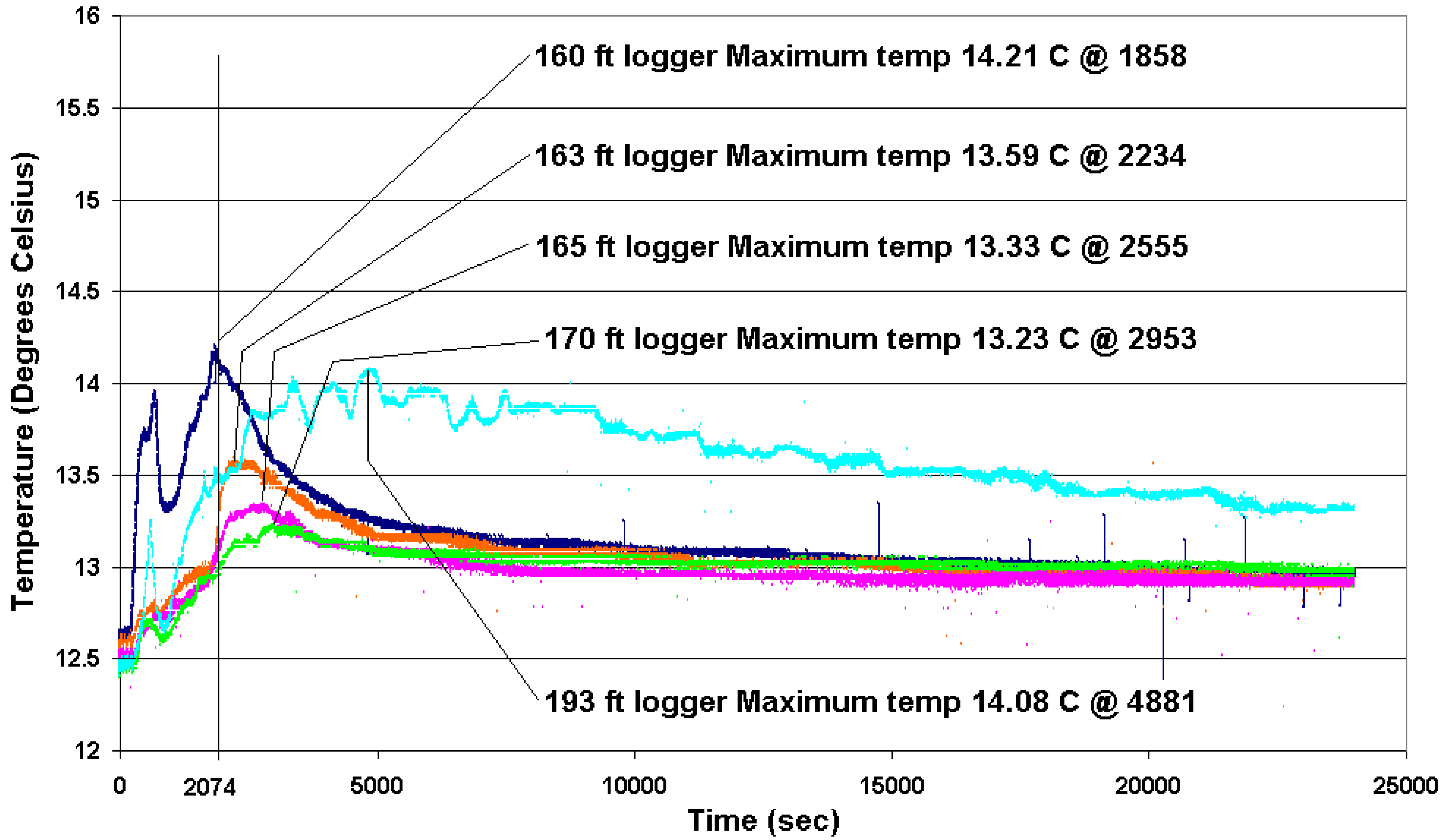

Figure A- 12 Plot of temperature for Point-Tracer Test 6. PT Test 6 was conducted with an initial injection rate of 2.6 gallons per minute. Data were collected on a one-second sampling interval. When flow began water temperature in tank was 46.1 C. Time t=0 corresponds to when flow began.

The first arrival time from Test 6 are contained in Table A-6.

Logger Depth (ft)	Arrival time from t=0 is start of flow (2-sec)	Arrival Temp C	Peak Temp C	Peak Temp Arrival Time (2-sec)
160	145	12.67	14.21	1858
163	246	12.61	13.59	2234
165	303	12.6	13.33	2555
170	322	12.53	13.23	2953
193	249	12.51	14.08	4881

Table A- 6 First arrival times of warm water tracer at temperature loggers in well UI#2 during Point-Tracer Test 6.

The arrival times for the upper most four data logger seem to adhere once again to the conceptual design of the point tracer test. The time between each data logger arrival time is sooner than in test five. This may be attributed to a slightly different position within the area of the 12” casing relative to test five. The different position maybe closer or more directly in the flow path of the tracer fluid.

A-1.18 Discussion of Point-Tracer Tests

Several important details concerning the possible flow paths of tracer fluid will be discussed in the following paragraphs. The 5” crack in the 12” casing, where water is flowing into the well, resides over a 38” circumference. The flow paths produced by the inflow of groundwater may carry the tracer in a plethora of directions. The odds of a point for measuring an increase in temperature of the tracer fluid located in the vicinity of the new flow paths created by the tracer and groundwater flow are very low. In addition to chaotic flow paths, there is a large thermal gradient created between the tracer fluid and the well water. Thermal dispersion may also decrease the odds of a point measurement recording an accurate temperature of tracer fluid relative to its position during migration. There would be a lag in arrive time between a temperature increase due to either physical or dispersal of higher temperature thermal migration. The logger would need to be in the flow path of the physical migration of tracer to adhere to the conceptual design of the point-tracer test. While a logger could be adjacent to the physical migration of the tracer and the proximal cooler well water would become heated over time by thermal dispersion. These two possible scenarios could be mislead when observing the measured arrived time for each data logger.

After test two an approximately 12” spool was added to the end of the suspension rope. During lowering of the logger series, the spool may have become lodged where the reduction in casing from 16” to 12” diameter is located. If this occurred that it would explain the disorder observed in arrival times recorded by the series of logger. A lower logger in the series would record a sooner arrival time the logger above. The lodging of the spool may also orient the loggers away from the center of the borehole, which could lower the odds of the logger recording the physical tracer arrival time.

A-1.19 Estimation of the Flow Rate in UI2

The average arrival times for Point Tracer Test 5 and 6 were used to estimate the rate (volume per unit time) of water flow down UI2. These tests were chosen because the results of the arrival times appear to be reasonable. An average of arrival times for the 193ft logger were not used because the values measured throughout the point tracer tests are of questionable quality.

Table A-7 contains the data that will be used to calculate the velocity of water movement in UI2.

Logger Depth (ft)	Average Arrival Time (sec)
160	182
163	270
165	335
170	375
193	n/a

Table A- 7 Average Tracer Arrival Times for Point Tracer Test 5 and 6

The flow rate was estimated from the velocity estimates. Because flow may occur between the 20"and smaller diameter casings, the flow rate also was estimated assuming all flow occurred in this annular space between the casing. Table A-8 lists the calculated flow rates between successive and non-successive loggers.

Logger Interval	Interval Length (ft)	Travel Time (sec)	Velocity (ft/min)	12" Flow (gpm)	20" Flow (gpm)
160ft-163ft	3	88	2.05	85.38	133.43
163ft-165ft	2	65	1.85	77.06	120.42
165ft-170ft	5	40	7.5	313.06	489.23
160ft-165ft	5	153	1.96	81.85	127.90
163ft-170ft	7	105	4	166.97	260.92
160ft-170ft	10	193	3.11	129.77	202.79

Table A- 8 Calculated Flow Rate in Well UI#2. The table presents a range of well bore flow velocities for Point-Tracer Tests 5 and 6. The interval length and travel time are used to calculate a velocity. Note that the velocity has been converted to feet per-minute for the conversion to a rate value in gallons per minute (gpm). The velocity is then multiplied by the circular cross-sectional area of the casing to derive a flow rate value.

The interval length is the distance in feet between each logger. The travel time in seconds is the time it took for the first arrival time of tracer to be recorded over the interval length between two data loggers.

Based on the interval lengths ranging from 2-10 feet, there appears to be a discrepancy associated with the 170ft logger. However, the range of estimated velocity appears viable given the assumption that the flow environment is not equal at a particular depth and cross sectional area of the well casing.

APPENDIX B

RECORD OF WELL UI#2 CLEANING ACTIVITIES

UNIVERSITY OF IDAHO WELL #6 PUMPING RECORD

Daily Notes on Events During Cleaning Operations

Day 1 Friday 02/10/06

-Cleaning started at 0815.

-Bailed UI2 down to 258ft.

-Bailed out grains of basalt.

-static water level 59.92ft

-bailing done for the day @ noon.

Day 2 Monday 02/13/06

- Bailing and brushing scheduled.

Day 3 Tuesday 02/14/06

-UI2 is bailed to a depth of 342ft.

-Both 16" and 12" are brushed.

-Pieces of casing are coming up in bailer. Samples of casing are recovers and logged.

-#1 sample collected from 333ft bls.

-#2 sample collected 342ft bls.

-Ran tag line down between the 20" and 16" casing and reached 103' bls.

Pumping UI2 starting @ 1100 to clean out suspended sediments for a better camera view.

-While pumping (80gpm) the water level in the well is remaining at 52' and have pumped for 30min.

-Water level in UI2 after pumping for 30min 52.2ft.

- Stopped pumping because sediments were clogging the pump.

-Train went by @ 1545 going westbound. Check on T16D for tidal efficiency effects.

Day 4 Wednesday 02/15/06

- Pumped out sludge from 1030am till 1100am.

- Stopped pumping because iron manganese sludge was plugging pump.

- Poured approx. 1000gal. down UI2. Directly from hydrant and from Water tank on the driller's rig.

- Second video inspection conducted to see if clarity improved

Notes B-1 Dailey notes recorded during each day of cleaning.

University of Idaho Well #6 Pumping Record

WELL #6 WATER USAGE RECORD				
DATE	PRESSURE	WATER METER READING	VARIABLE FREQUENCIES (Hz)	INITIALS
2/1/2006	0	4943720	0	SB
2/2/2006	0	4943720	0	SB
2/3/2006	0	4943720	0	CS
2/4/2006	0	4943720	0	SB
2/5/2006	0	4943720	0	SB
2/6/2006	0	4943720	0	CS
2/7/2006	0	4943720	0	SB
2/8/2006	0	4943720	0	SB
2/9/2006	0	4943720	0 -> 57	SB
2/10/2006	0	4952470	0	DM
2/11/2006	0	4952470	0	CS
2/12/2006	0	4952470	0	CS
2/13/2006	0	4952470	0	CS
2/14/2006	0	4952470	0	SB
2/15/2006	0	4952470	0	CN
2/16/2006	0	4952470	0 -> 57	SB
2/17/2006	0	4960970	0	CS
2/18/2006	0	4960970	0	SB
2/19/2006	0	4960970	0	CS
2/20/2006	0	4960970	0	CS
2/21/2006	0	4960970	0	SB
2/22/2006	0	4960970	0	SB
2/23/2006	0	4960970	0 -> 57	SB
2/24/2006	0	4981260	0	CS
2/25/2006	0	4981260	0	SB
2/26/2006	0	4981260	0	SB
2/27/2006	0	4981260	0	CS
2/28/2006	0	4981260	0	SB

Table B- 1 Pumping records for well UI#6.

	WELL #6 WATER USAGE RECORD			
DATE	PRESSURE	WATER METER READING	VARIABLE FREQUENCIES (Hz)	INITIALS
3/1/2006	0	4981260	0	SB
3/2/2006	0	4981260	0	SB
3/3/2006	0	4981260	0	DM
3/4/2006	0	4981260	0	CS
3/5/2006	0	4981260	0	CS
3/6/2006	0	4981260	0	CS
3/7/2006	0	4981260	0	SB
3/8/2006	0	4981260	0	SB
3/9/2006	0	4981260	0	SB
3/10/2006	0	5124780	57	DM
3/11/2006	0	5124780	0	SB
3/12/2006	0	5124780	0	SB
3/13/2006	0	5124780	0	CS
3/14/2006	0	5124780	57	CS
3/15/2006	0	5158040	0	CS
3/16/2006	0	5158040	0	CS
3/17/2006	0	5158040	0	CS
3/18/2006	0	5158040	0	SB
3/19/2006	0	5158040	0	SB
3/20/2006	0	5158040	0	CS
3/21/2006	0	5158040	0	SB
3/22/2006	0	5158040	0	SB
3/23/2006	0	5158120	0	SB
3/24/2006	0	5158120	0	DM
3/25/2006	0	5158120	0	CS
3/26/2006	0	5158120	0	CS
3/27/2006	0	5158120	0	SB
3/28/2006	0	5178870	0	CN
3/29/2006	0	5178870	0 -> 57	SB
3/30/2006	0	5178870	0 -> 57	CS
3/31/2006	0	5178870	0	SB

Table B- 1 continued

APPENDIX C

UI2 VIDEO LOG NOTES

UI2 Video Review

16”casing		Notes
- 1-6 casing joints depth of	46.1ft	-all in good condition.
- Static water level	50.3ft	
- 7th casing joint	63.5ft	- in places weld is got.
- 8th casing joint	65.0ft	- more area of weld is got that 7th
- 9th casing joint	82.5ft	- good condition
- 10th “	84.7ft	- weld is completely gone
- Perforations in casing base on well log are from 60ft – 90.5ft. None observed.		
- 11th casing joint	102.2ft	- small area of weld gone
- 12th casing joint	103.9ft	- 50% of weld gone, precipitate at joint.
- 13th “	120.4ft	- good condition
- 14th “	122.0ft	- large portion of weld gone.
- Possible perforation ~ 1.5ft in length @ 137.7 to 138.4ft.		
- 15th casing joint	139ft	- linear corroded feature possible perforation.
- 16th “	140.0ft	-some holes in joints.
- 17th “	157.0ft	- appears to have turbulent flow
- 18th “	159.0ft	- suspended particles effected by flow coming into well.
- Casing reduction.		
12” casing		
- 1st casing joint	193.9ft	- flow out of casing
- Hole in casing	198.5ft	- hole is not associated with casing joint.

- @ 190.0ft to 275ft perforated casing according to well log.

- @ 195.6ft small hole in casing. Flow out of 12” casing.

- @ 211.3ft beginning of large hole in casing.

- @ 212 turbulent flow within hole in casing.

- Bottom of hole at 212ft, have visual of 20” casing on the outside of the 12” casing. At bottom of hole in casing large size diameter grains filling space between 12”casing. Grain size ~ 2cm length of medial axis.

- Slots observed in 20” casing @ 213.6ft.

- From 211.3ft to 117.1ft the 12” casing is completely gone.

- Casing is riddled with holes from 211.3ft to 237ft.

- Hole observed from 243ft to 245ft. Hole in 12” and 20” casing. Flow is out of casing.

- Scale observed around entire circumference of casing. No holes observed in casing below ~ 270ft.

- Sediment filled to a depth of 322.0ft

- From 211ft to 220ft large amount of scale is falling down well in areas of large perturbations in casing. The scale is observed falling between the 12” and 20” casing.

Notes C-1* Notes taken from two video logs recorded from UI2 Well.